AD 739585

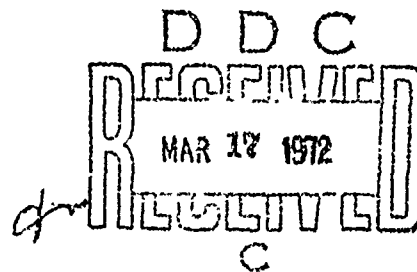# STUDY TO DEFINE THE INTERFACE AND OPTIONS FOR THE ADVANCED SIMULATION IN UNDERGRADUATE PILOT TRAINING VISUAL SIMULATOR

JOSEPH A. JUHLIN, ET AL

GENERAL ELECTRIC COMPANY

TECHNICAL REPORT AFHRL-TR-71-47

SEPTEMBER 1971

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Apollo and Ground Systems General Electric Company Daytona Beach, Florida	Unclassified
	2b. GROUP ---

3. REPORT TITLE

STUDY TO DEFINE THE INTERFACE AND OPTIONS FOR THE ADVANCED
SIMULATION IN UNDERGRADUATE PILOT TRAINING VISUAL SIMULATOR

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final—December 1970 to May 1971

5. AUTHOR(S) (First name, middle initial, last name)

Joseph A. Juhlin, et al

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1971	140	1

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
F33615-71-C-1211	71DBF017.(e)
b. PROJECT NO 686F, Unit A	
c. Work Unit: 686F OA 010	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFHRL-TR-71-47
d.	

10. DISTRIBUTION STATEMENT

Approved for Public Release;
Distribution Unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Details of illustrations in this document may be better studied on microfiche	Air Force Human Resources Laboratory Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

As a result of recent Air Force decisions regarding the Advanced Simulation in Undergraduate Pilot Training (ASUPT) Flight Simulator requirements and configurations, the need for additional definition of the visual subsystems interface parameters became apparent. It was also recognized that certain new features to improve the system operational flexibility and performance needed further study and definition.

In the study to define the interface and options for the ASUPT visual simulator, four major areas were investigated. These specific areas are:

a. CRT Electronics Definition
b. CRT Electrical Characteristics
c. Display Multiplexing
d. Edge Smoothing

The CRT Electronics Definition and the CRT Electrical Characteristics investigations concentrated on establishing feasible design parameters consistent with system performance requirements and on identifying a compatible interface between the CRT (including focus and deflection coils) and the Display Electronics. The CRT Electronics Definition included sweep generator and deflection amplifiers, linearity correction circuits, and dynamic brightness as well as focus circuits, video amplifiers, and

(Continued)

DD FORM 1473 (1 NOV 64)

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
visual simulation						
computer image generation						
simulation						
CRT electronics						
cathode-ray tubes						

AFHRL-TR-71-47

STUDY TO DEFINE THE INTERFACE AND OPTIONS FOR THE ADVANCED SIMULATION IN UNDERGRADUATE PILOT TRAINING VISUAL SIMULATOR

JOSEPH A. PUHLIN, ET AL

FOREWORD

This report summarizes the results of the study conducted by the General Electric Company at Daytona Beach, Florida, under contract No. F33615-71-C-1211, "Study to Define the Interface and Options for the Primary ASUPT Visual System." It is a part of the advanced development project "Innovations in Training and Education," project 686F, unit A. The study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory. Period of the study was from December 1970 to May 1971.

The contract monitor was James D. Basinger, Advanced Systems Division (AFHRL/TRS).

This document has been reviewed and approved by:

Gordon A. Eckstrand, PhD
Division Chief AFHRL/TR
Advanced Systems Division
Air Force Human Resources
    Laboratory

ABSTRACT

As a result of recent Air Force decisions regarding the Advanced Simulation in Under-graduate Pilot Training Visual Simulator Flight Simulator requirements and configurations, the need for additional definiton of the visual subsystems interface parameters became apparent. It was also recognized that certain new features to improve the system operational flexibility and performance needed further study and definition.

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The CRT Electronics Definition and the CRT Electrical Characteristics investigations concentrated on establishing feasible design parameters consistent with system performance requirements and on identifying a compatible interface between the CRT (including focus and deflection coils) and the Display Electronics. The CRT Electronics Definition included sweep generator and deflection amplifiers, linearity correction circuits, and dynamic brightness as well as focus circuits, video amplifiers, and power supplies. The Display Multiplexing and Edge Smoothing investigations were directed toward concept definition of optional features to improve the system operational flexibility and performance.

The CRT Electronics Definition was complicated by the unique requirements placed on the CRT and on the close interrelationship of the CRT characteristics with the CRT electronics design parameters. Close coordination was maintained between the two parallel studies to define the CRT parameters and the CRT Electronics Parameters to assure a compatible interface and to assure implementation feasibility. The study provided a better understanding of the ASUPT display design requirements and re-sulted in a technical specification for both the CRT Electronics and the CRT.

The Display Multiplexing investigation consisted of two distinct elements. The first was concerned with techniques for multiplexing a single computed image generator with two separate cockpit display subsystems, and the second was a subjective evalua-tion of the effects of apparent motion discontinuties resulting from time multiplexing. The concept analysis resulted in the definition of two feasible approaches for driving two cockpit displays with one image generator referred to as Time Multiplexing and Edge Capacity Multiplexing. In the Time Multiplexing concept, the computed image generator alternately updates each cockpit display subsystem resulting in a reduction of the update rate from 30 updates per second to 15 updates per second while still refreshing the 2:1 interlaced display at 30 times per second to prevent flicker. The edge capacity concept shares the system scene generation capacity between the two cockpit displays resulting in reduced scene content capacity in each cockpit display. The subjective evaluation of motion discontinuities associated with the reduced update rate inherent in time multiplexing demonstrated that severe operational constraints would be imposed if this technique were implemented.

iii

The Edge Smoothing study evaluated several techniques for improving the discontinuities in edges intersecting the raster lines at angles other than 0 to 90 degrees. The results of this study indicate that when all the techniques are simultaneously applied, the residual effect is negligible.

SUMMARY AND CONCLUSIONS

PROBLEM

The Computer Image Generation (CIG) System for Advanced Simulation in Undergraduate Pilot Training (ASUPT) was defined in the study conducted on Contract No. F33615-69-C-1883. However, the interface of the CRT electronics and display CRT required further definition before the procurement of the CIG System. Also, two options required study and definition which would improve the utility of CIG and improve the subjective appearance of the CIG display.

APPROACH

This study was divided into four areas:

    a.   CRT Electronics Definition.

    b.   CRT Characteristics Definition.

    c.   Display Multiplex Study and Definition.

    d.   Edge Smoothing Study and Definition.

The CRT electronics and CRT characteristics were closely coordinated to insure that the results were compatible and would interface. The display multiplex study consisted of two parallel efforts: (1) analytic study and (2) synthesizing a "time" shared multiplexed display. The edge smoothing effort primarily studied the effects of various approaches to smoothing edges at an angle with the scan lines of the display.

RESULTS

The CRT electronics and CRT characteristics were defined for the ASUPT system. The "time" shared multiplex was found to be unsuitable for high angular and linear rates of motion. But the "edge" sharing approach is feasible and would improve utility if low detail is acceptable. The smoothing of edges can be accomplished by: (1) increasing the number of scan lines and line elements, (2) increasing the transition time from one shade to another shade, and (3) reducing the contrast of the shades on each side of the edge.

CONCLUSIONS

The results of this study resolved potential problems in the application of CIG to ASUPT.

This summary was prepared by James. D. Basinger, Simulation Techniques Branch, Advanced Systems Division, Air Force Human Resources Laboratory.

v

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

SECTION I

INTRODUCTION

The objective of this study was to define certain interfaces and options for the Advanced Simulation in Undergraduate Pilot Training (ASUPT) visual simulator. Sufficient synthesis and analysis were required to allow specification and definition of the performance and interface requirements associated with the CRT and the CRT electronics, to establish concepts and feasibility for improved image quality by edge smoothing, and to establish concepts and feasibility for display multiplexing.

This report addresses four specific areas of investigation:

a. <u>CRT Electronics Definition</u>—The objective of this task was to define the CRT electronics equipment to the extent necessary to assure technical feasibility, to establish the required interface compatibility with the CRT, and to quantify the parameters that influence the interface with the flight simulator.

b. <u>CRT Electrical Characteristics</u>—The objective of this task was to define the CRT electrical design parameters consistent with system performance requirement and compatible with feasible CRT electronics design parameters.

c. <u>Display Multiplexing</u>—The task had two objectives. The first was concerned with techniques for multiplexing a single image generator with multiple display subsystems, and the second was the subjective evaluation of the effects of motion discontinuities resulting from multiplexing.

d. <u>Edge Smoothing</u>—The objective of this task was to investigate methods for smoothing the transition from one side of the edge to the other throughout all raster lines intersected by the edge.

Each of these areas was investigated with the resulting conclusions detailed in Sections 3, 4, 5, and 6, respectively.

SECTION II

SUMMARY

2.1 INTRODUCTION

This section contains a summary of the results of the study to define the interface and option for the ASUPT visual simulator. Four specific areas were investigated during this study: two areas pertained to the CRT and associated CRT electronics; a third area was concerned with multiplexing techniques and the subjective effects of resultant motion discontinuity: and the last was concerned with methods for edge smoothing.

2.2 CRT ELECTRONICS DEFINITION

The ASUPT visual system configuration was studied to determine the impact of the overall system requirements on the CRT electronics. Based on this analysis, along with the inputs from the CRT characteristics analysis task. a basic CRT electronics configuration was formulated. After analyzing the functional interfaces and the electronic signal parameters, a preliminary specification was made for the CRT electronics.

The hardware definition phase generated a physical configuration for the CRT electronics showing all pertinent interfaces. Additionally, a list of electronic signal parameters was generated to study each functional interface. An expected range of parameters was determined for each electronic component block, with particular emphasis on the video and deflection amplifiers, to determine the required adjustments for the electronics components. A summary of the physical parameters is used with the electronic signal parameters to provide a technical specification.

The CRT image alignment requirements were studied, and a philosophy was developed for alignment implementation. A preliminary alignment method is described to permit a first-order alignment.

To further clarify the geometry of the CRT and the Farrand window optics, a scale model was made of the CRT raster. The model was helpful in generating much of the raster correction philosophy as well as the alignment philosophy. In addition, this was verified by demonstrating that it will indeed produce a uniform rectilinear grid when the raster grid is mapped from the spherical CRT faceplate surface to the tangent plane.

Based on the data inputs from the CRT characteristics task and the preceding analyses, it is concluded that the brightness and resolution requirements are feasib'e. Analysis of the test CRT at 4 milliamperes peak beam current shows it would produce an ASUPT display brightness of 4.16 footlamberts. Thus, unless Farrand window transmission is increased, the beam current must be increased to 5.77 milliampere. to achieve a 6 footlambert display brightness.

A specific choice of focus and deflect components should be made based on experimental verification. Since the present resolution test data was obtained with a high inductance yoke, this data should be retaken with the yoke which is finally selected.

More complete test data is required on the CRT spot size versus beam current at beam currents of at least 6 milliamperes. Over a range of field angles using the final choice yoke, experimental tests should be run to determine the characteristics of the focus (video) requirements.

There is a need to redesign the CRT cathode lens for better life and lower drive requirements. Initial study indicates 150-volt video swing is within state-of-the-art at 20 to 40 MHz, but the requirement of 200 volts swing will require additional work and will involve much higher power vacuum tubes.

The electronic signal parameters (including specifically regulation and stability) are approximate and require a perturbation analysis to determine final design requirements.

2.3 CRT ELECTRICAL CHARACTERISTICS

This investigation was directed toward the definition of the primary design and performance parameters for an unique CRT designed specifically to interface with an In-Line Infinity Optical Assembly (Pancake Window). The CRT required for the ASUPT visual system is unique in that it substantially exceeds in diameter, screen area, and total luminous emission, of any CRT hitherto developed. The study program was organized to investigate the physical and mechanical, electrical, brightness and optical, and life parameters of the CRT design.

To obtain data on key parameters which were accurately representative of ultimate performance, special experimental CRTs were built and tested to incorporate design features very closely approximating those required for the final CRT.

The results of the CRT study appear to be most encouraging and confirm that an acceptable minimum performance level has been demonstrated. The envelop design aspects are especially favorable in view of the options and alternatives which are now available. With the available choices now defined, the technical feasibility for fabrication of satisfactory envelopes has been established.

Screen brightness and resolution results indicate that with an increase in beam current of up to 6 milliamperes, adequate resolution should be available at a 1,000 footlambert area brightness level. Adequate options appear to exist with regard to selection of an optimum phosphor screen. A final choice is unlikely to require any new materials development.

The results of the life test study suggest that a continuation of study and development is required to confirm the tentative conclusions. Additional tubes should be built employing the largest available envelopes and incorporating increased getter yields and extended exhaust processing. With this additional development work, it is considered probable that the P6M10 life can be predicted at between 5000 and 10,000 hours.

2.4 DISPLAY MULTIPLEXING

This task established the feasibility of multiplexing two cockpit displays from a single ASUPT image generation system and scoped the impact on the basic system design. Two investigations were made in parallel to achieve this determination—the system organization and hardware requirements investigation and the motion discontinuity effects investigation.

4

Time-multiplexing, edge capacity multiplexing, and dual mode multiplexing were investigated to determine applicability to the ASUPT visual system. The analysis proved from the system configuration and implementation aspects that each multi-plexing capability is feasible and that a practical approach exists in each case. The decision to add a time multiplexing capability to the ASUPT visual system is essen-tially a tradeoff of cost versus incremental training capability including consideration of the motion discontinuity effects.

The motion discontinuity effects investigation was an experimental evaluation of the visual effects resulting from the reduced motion update rates inherent with time multi-plexing. A video recording was made from a real time CGI system installed at the Electronics Laboratory in Syracuse, New York. Scenes of aircraft maneuvers rang-ing from taxiing to low-level high-speed aerobatics were recorded with 30 and 15 frame per second motion update to allow subjective comparisons of effects.

The reduced update rate produced objectionable motion discontinuity effects in maneu-vers requiring pitch, roll, and gain rates of over 20 degrees per second. The higher the rates, the more objectionable the effects. It appears that this capability should not be considered as an option unless a significant portion of the training program is dedicated to maneuvers, such as takeoffs, landings, approaches, taxiing, where the effects are minimal.

This conclusion is supported by considerable experience in flying the NASA II visual system in Houston, Texas, which uses 20 hertz update and refresh rates, and in flying the real time systems at the Electronics Laboratory and Apollo and Ground Systems with the 15 hertz update rates.

2.5 EDGE SMOOTHING

This investigation considered various techniques to improve the discontinuities in edges intersecting the raster lines at angles other than 0 or 90 degrees.

The following techniques were evaluated:

 a. Transition Time Control.
 b. Element Size Change.
 c. Contrast Change.
 d. Edge/Scan-line Orientation.
 e. Scan-line Width.

Each technique was evaluated using dynamic scenes. Film sequences were made for srojective evaluation of the various techniques.

The study indicates that when all the techniques are simultaneously applied and adjusted to optimum, the residual step effect is negligible.

SECTION III

CRT ELECTRONICS DEFINITION

3.1 INTRODUCTION

3.1.1 PURPOSE OF STUDY

The purpose of this study was to define the CRT electronics portion of the ASUPT visual simulation system in sufficient detail to allow specification of CRT electronics performance requirements and to allow definition of the interface parameters which influence and constrain the flight simulator design. Of particular interest were the components that mount on the motion platform and the adjustments and controls required for display alignment. The CRT electronics definition is complex because of the unique requirements placed on the CRT and the close inter-relationship of the CRT characteristics with the CRT electronics design parameters. The definition of the CRT electronics proceeded in parallel with the definition of CRT characteristics undertaken by Thomas Electronics under subcontract to General Electric. The results of the CRT characteristics study is documented in the following section of this report. Close coordination was maintained with Thomas Electronics in obtaining the CRT parameters necessary for the CRT electronics study.

3.1.2 SCOPE

Specific goals of this study were:

a. Definition of the electronics which interface with the display CRT, with emphasis on the components to be mounted on the motion platform. This definition included estimates of weight, size, mounting location constraints, X-ray radiation level, and cooling and cabling requirements.

b. Assure feasibility of the CRT electronics based on CRT interface requirements.

c. Identification of the variables relating to electronic alignment of juxtaposed images. Development of a method of alignment and recommendations for the location of electronic adjustments required to affect the alignment.

The effort to meet the study goals can be categorized into two areas. The first was the determination of parameters and the definition of CRT electronic equipment. The second concerned the definition of parameters for alignment of the CRT images and CRT electronics. The types of functional components included in the CRT electronics study are.

a. Sweep generator.
b. Linearity correction generator.
c. Dynamic brightness and focus circuits.
d. Deflection amplifier.
e. Video amplifier.
f. Anode power supply.
g. Low voltage power supplies.
h. Cables.
i. Adjustment controls and circuits.

Performance and physical parameters associated with each functional component in the above list are intimately related to the CRT characteristics, and in turn, many of the parameters (i.e., size, weight, mounting constraints, cooling, adjustment control location, etc.) directly impact the flight-simulator design.

In order to assure a compatible interface between the CRT electronics and the CRT (including deflection and focus coils), close coordination between General Electric (performing the CRT electronics definition task) and Thomas Electronics (performing the CRT characteristics task) was maintained. Trade studies were made as necessary to assure economic and technical feasibility of both CRT and CRT electronics parameters.

After establishing the required parameters for the CRT electronics equipment, a preliminary design configuration was generated to define the necessary parameters influencing the flight simulator design. No attempt was made to define the actual physical interface since this will be the prerogative of the flight simulator manufacturer. But rather, the parameters that influence the design (weight, size, location constraints, etc.) were identified. The design configuration also includes identification of setup and alignment controls as well as recommended location, with particular emphasis on controls to be located in the cockpit.

This report documents the results of the task. Paragraph 3.3 includes recommended interface specifications with appropriate parameter ranges identified which include consideration for normal deviations during the hardware design of the CRT electronics equipment.

3.1.3 SYSTEM REQUIREMENTS

The display electronics definition is sufficient to establish the feasibility of electronic design to operate with the computed image generator and the CRT and display optics. The system requirements which formed the basis for the display electronics parameters and the CRT characteristics are:

a.   Highlight brightness   6 footlamberts

b.   Brightness variation   Less than 50 percent over entire field-of-view, and less than 25 percent across adjacent channel joints

c.   Geometric distortion

Angle	Tolerance
5 degrees or less	6 minutes of arc
5 degrees to 100 degrees	2 percent
Over 100 degrees	2 degrees

d.   Linearity Error   Less than 1 degree over the entire field-of-view

e.   Image discontinuity   The discontinuity between two adjacent facets shall be less than 1 degree at nominal eye position

f.   Scan rate   1023 lines

g.   Elements per scan   1000 elements

3.1.4 APPROACH AND RESULTS

The general approach taken, in this study of the ASUPT CRT electronics, was first to study the ASUPT visual system configuration as described in Paragraph 3.2. A major importance and priority was placed on determining the impact of the overall system requirements on the CRT electronics system. A basic, feasible CRT electronics concept was then formulated consistent with this visual system. A functional interface was prepared, which guided a methodical study of the CRT electronics system by considering each functional interface, one at a time.

Next, a list was made of the pertinent electronic signal parameters for the CRT electronics system. Then each functional interface was considered versus the list of electronic signal parameters. A form of matrix chart was prepared and employed to study each functional interface. At this point a preliminary specification was made of the CRT electronics system by specifying the required value, waveshape, etc., of each electronic signal parameter.

Following the functional interface portion of the study consideration was given to the hardware definition. This hardware definition included the generation of a physical configuration for the CRT electronics system including the CRT, CRT coils, shields and circuit blocks. A list of physical parameters was generated and used as in the previous matrix charts to examine each functional interface in the light of the pertinent physical parameters. A range or expected range of equipment physical parameters was determined for each electronic component block. The greatest emphasis was given to the video amplifier and the deflection amplifier. Here some preliminary design was initiated, but time did not permit much progress. These analyses generated the detailed equipment physical parameters; such as approximate weight, power and similar parameters. A summary of these parameters is used together with the electronic signal parameters to provide a technical specification. This specification is listed as a separate entity in Paragraph 3.5 of this report.

In the course of the alignment study some thought was given to an alignment philosophy. This alignment concerns first aligning each individual CRT system and then the alignment of seven CRT systems in the overall visual system. This alignment philosophy was developed in an iterative fashion. First, through consideration of the functional interface chart, a preliminary alignment method was formulated, but as analyses yielded a better definition of the various corrections required, this was fed back into the alignment method with a resulting change. Thus, at the conclusion of this study, a preliminary alignment method or procedure has evolved which can permit a first-order alignment. This procedure is based strictly on study alone and cannot hope to compete with a procedure derived from a working CRT test setup, but it does at least yield an overall CRT electronics system which should be capable of correcting for all the known or expected conditions in the eventual ASUPT visual system environment.

This CRT electronics study has provided a much better understanding of the ASUPT display design requirements, resulting in a Technical Specification for the CRT electronics system; however, there are several areas which deserve some additional consideration. It was not possible to generate a complete error analysis which would yield a set of rigid bounds for purposes of setting specifications. Consequently, some of the Technical Specifications are not as accurate a statement of required performance as if derived from an error analysis. For the same reason in some cases, the limits of expected performance in the Technical Specification are broad. A second and very important point is that the scope of this study did not permit circuit development work, thus some findings and recommendations of the study are based on past experience.

3.2 SYSTEM CONFIGURATION

3.2.1 OVERALL CONFIGURATION—COMPUTER, CRT ELECTRONICS, CRT WINDOWS

The overall configuration of the ASUPT system is depicted in schematic form in the block diagram of Figure 1.

3.2.1.1 Image Generation Computer

In the ASUPT system the image generation computer synthesizes the video signals which are sent to the individual cathode ray display tubes. The parameters of the image generation system which are important when considering the interface with the CRT electronics system are:

    a. **Raster Format**

        30 frames per second
        1000 lines nominal, 2:1 interlace
        1000 elements nominal, element rate, 40×10^{6} per second

    b. **Gray Shades**

        5-bit code (32 levels from black and white)

    c. **View Orientation**

        The sight line direction and raster orientation are independently programmable for each view to facilitate alignment of the computer images and the display channels.

3.2.1.2 Display Subsystem

The display subsystem accepts video and synchronizing signals from the image generating equipment and presents a wide field of view to the pilot in a T-37 simulator cockpit. The display subsystem mounts around the cockpit to the motion platform and consists of seven channels mosaicked to form a continuous field of view.

The optical channels of the display consist of in-line (pancake) windows, a Farrand Optical Company development. These are compact, virtual image projection optics which present light collimated images. Each optical window is driven by a cathode ray tube which is external to the optical assembly and in-line with its optical axis. This property of the window allows adjacent facets to be added without physical interference. Optically, the entire assembly of windows forms a concentric arrangement about the eye point, and the spherical sections of the collimating mirrors join to form a continuous surface. The T-37 cockpit requires a window with very large eye relief to avoid interfering with major elements of the cockpit. The display therefore requires the development of large optical components and a large CRT in order to minimize the number of channels required. This minimization occurs by using pentagonal facets in a regular dodecahedron configuration. The facets of a dodecahedron subtend an angle which is the largest that can be used without serious loss of resolution with a 1000-line display.

The performance of the display subsystem is primarily determined by the Farrand windows and the cathode ray tubes. Since neither of these display components has been built in the large size required by the ASUPT Program, the projected performance

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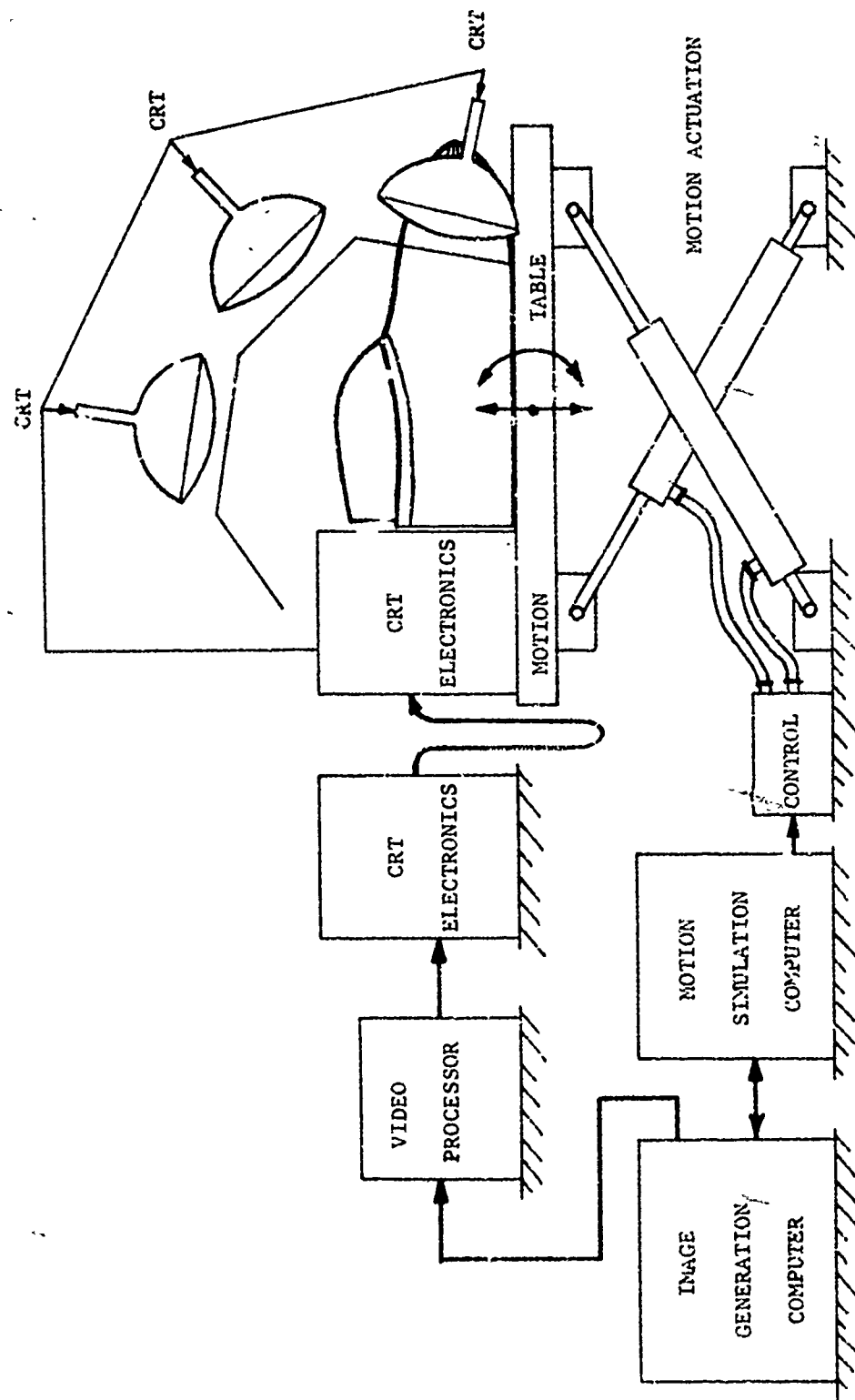
Figure 1. Block Diagram ASUPT System

is extrapolated from existing smaller components. In general, the performance is limited by the Farrand window; the transmission of the wanted image is low; the transmission of the unwanted ghost images at large off-axis angles is relatively high: and for the CRT, obtaining a sufficiently bright image for input through the low transmission display window is difficult. (Additional background information for the following three subsections 3.2.2, 3.2.3, and 3.2.4 is contained in the final report entitled "System Definition Study for the Primary Visual Simulation System for the ASUPT Program" for contract number F33-615-69-C-1883.)

3.2.2 FARRAND WINDOW

The display subsystem is fed video signals from the image generation computer system to provide an exceedingly wide field-of-view with an image at infinity for the student pilot. Figure 2 shows the Farrand window and a CRT in a scaled drawing of the ASUPT display. This sketch shows a cross-section taken on a plane passing through a pentagon point and pentagon center of one of the display channels.

The individual windows will be aligned for the proper angular relationship. The critical alignment involves placing of the CRT relative to the window and electronic alignment of the raster. Alignment adjustment will provide less than 1 degree image discontinuity at the boundary between channels.

At present, no data has been available regarding the exact nature of the probable image distortion present in the window, thus the tentative distortion correction in the CRT electronics must possess a reasonable degree of freedom to fit a range of distortion functions.

To better understand the relation between the field-of-view of the window and the CRT raster one can determine from Figure 2 that the CRT illuminates a greater field-of-view than can be seen through a single window with the eye place at the eye point. This excess field is necessary to permit the observer's eye to move off the nominal eye point and still obtain a realistic display. In Figure 3, the channel axis is designated by a dot and the normal field boundary as viewed from the nominal eye point by solid lines. On Figure 3, the limits of the field-of-view with the eye at the position of maximum field angle are designated by dashed lines. On the CRT the raster shown by dotted lines is so adjusted to bring the nominal raster to a size where the pentagonal points lie in the CRT chordal plane.

A curve of window transmission versus field angle for a P-20 phosphor with little blue output is plotted in Figure 4. In view of the physics of the window, the transmission is most likely a monotonic function which allows the approximation of the window function with three points. After exact data on the window is available, the integral of the curves weighted by the phosphor spectral characteristic should be used to obtain the required correction curve. Note that the relative transmission is rather uniform over much of the field, but at field angles in excess of 30 degrees or so the transmission falls rapidly. This transmission fall-off with field angle will result in serious shading in the display image presented to the observer and requires correction in the CRT electronics to yield a uniformly bright image.

Variations in spectral transmission over an individual window can be ±15 percent with similar variations from one window to the next. If the variations in window transmission are smoothly varying center symmetric functions, correcting for the resulting departure of the output display from uniform brightness is eased.

12
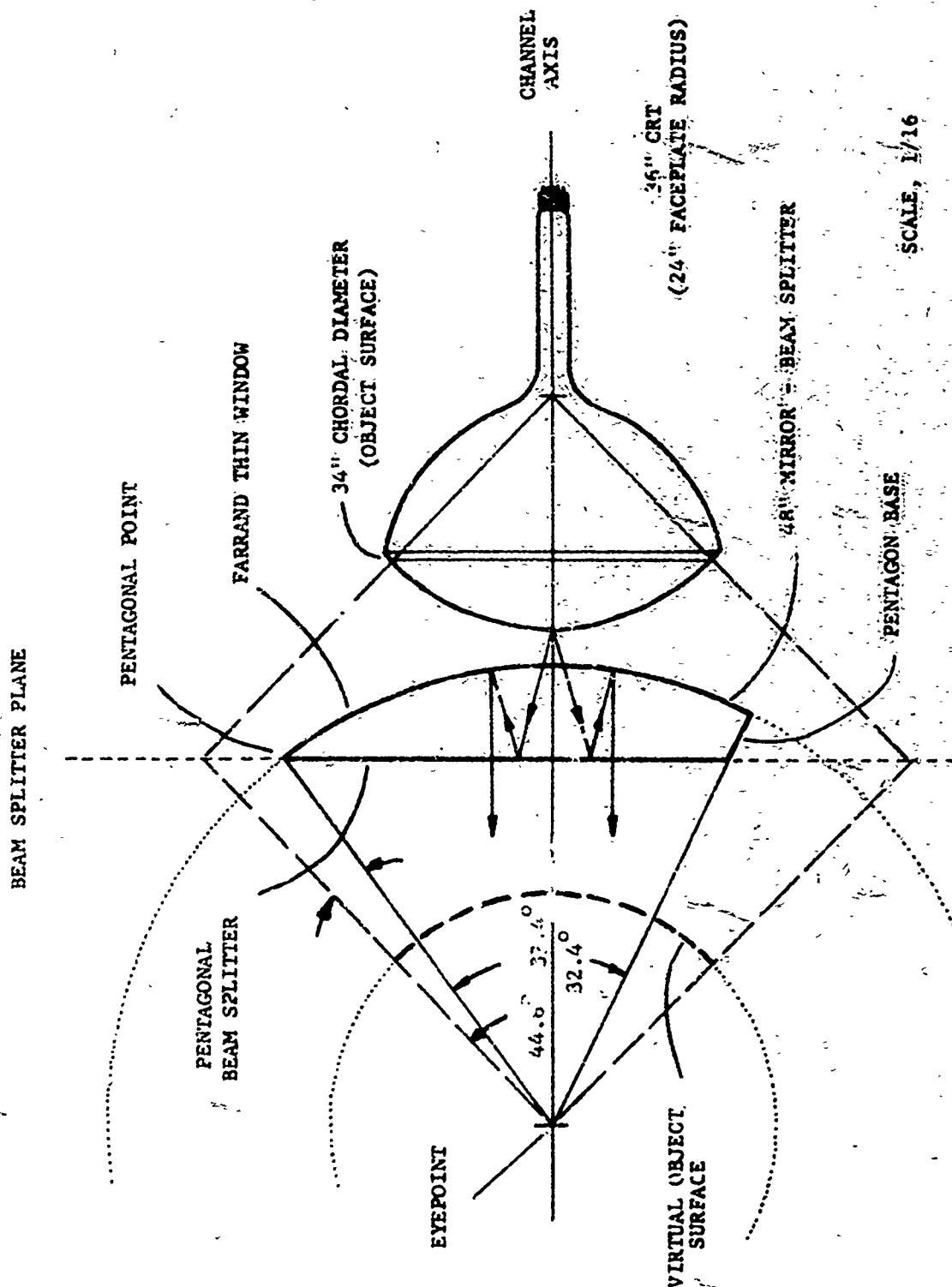
Figure 2. ARUPT Display Window and CRT Configuration

BEAM SPLITTER PLANE

PENTAGONAL POINT

FARRAND THIN WINDOW

34" CHORDAL DIAMETER
(OBJECT SURFACE)

CHANNEL
AXIS

25" CRT
(24" FACEPLATE RADIUS)

48" MIRROR - BEAM SPLITTER

PENTAGON BASE

SCALE, 1/16

PENTAGONAL
BEAM SPLITTER

44.6°
37.4°
32.4°

EYEPOINT

VIRTUAL OBJECT
SURFACE

13

VIRTUAL
CRT
RASTER

LIMITS OF FIELD OF VIEW
(NOMINAL EYEPOINT)

LIMITS OF FIELD OF VIEW
(EYEPOINT OF MAX. FIELD ANGLE)

Figure 3. Virtual Object Surface

14
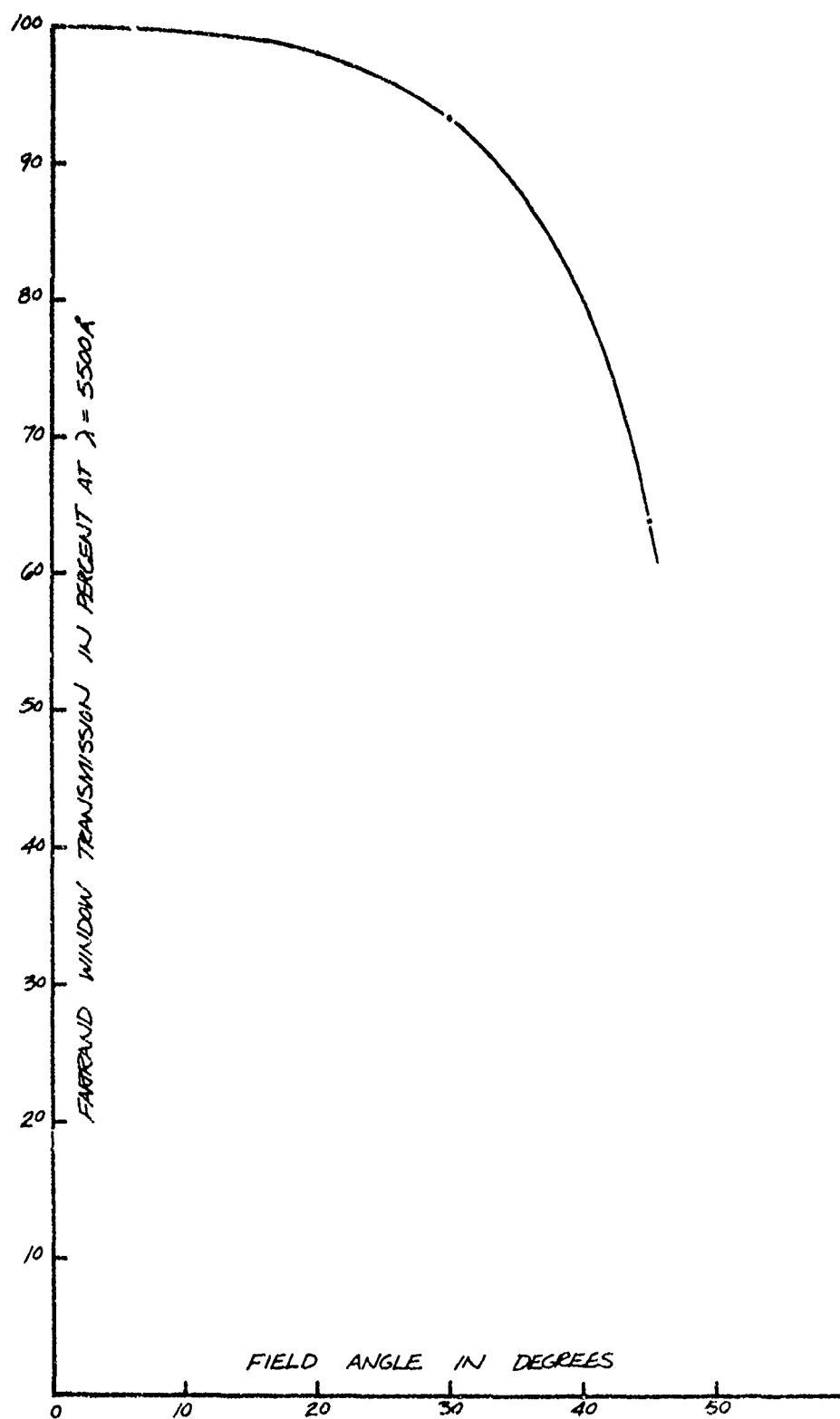
Figure 4. Approximate Window Transmission T(W) versus Field Angle
(Wanted Image—38-inch Window)

15

3.2.3 CATHODE RAY TUBE

The cathode ray tube (CRT) is the object forming element of each channel; as such the general requirements are dictated by the performance specifications of the Farrand window in the ASUPT configuration.

3.2.3.1 Initial CRT—CRT Electronics Trade-off Criteria

The present study has consisted of a coordinated effort on the CRT and CRT electronics system design. Both studies were initiated with a working meeting to determine with greater certainty the general range of specific CRT parameters. Attendees included representatives of Thomas Electronics, Syntronics, and General Electric Company. Several analyses were carried out to effect a tradeoff between limiting deflection distortion aberrations and deflection circuit requirements by calculating the expected off-axis spot growth. In general, the off-axis resolution performance of a CRT will be limited by the deflection yoke aberrations. The off-axis spot growth is a strong function of the deflection angl and a number of other factors which affect field uniformity within the yoke. Yoke construction and size will affect spot growth. Normally a larger neck diameter or yoke size will yield better off-axis performance, but at the cost of greater drive power.

A list of initial CRT parameters selected as a result of the meeting is given in Table I.

Table I

CRT PARAMETERS WHICH AFFECT CRT ELECTRONICS
(INITIAL TRADE-OFF ESTIMATES)

a.	Screen voltage	35 kv
b.	CRT (maximum) deflection angle	70 degrees total (35 degrees half angle)
c.	Deflection yoke	Metal (laminated stator)

Horizontal Coil

Yoke inductance	70 μh
Yoke current	15 amperes
Flyback time	6 μsec
Forward voltage	82.5 volts
Flyback voltage	350 volts
Physical dimensions	2.5 inch ID × 4.0 inches long

Additional items of interest are summarized as follows. Higher inductance yokes up to about 100 μh yield improved spot shape by producing a more uniform deflection field through the use of improved turns distribution. The deflection field does not exactly follow the current drive immediately after a step current change. The maximum error due to tailing off in the field would be approximately 1 percent after 18 microseconds. The form of deflection yoke, a laminated metal stator, was selected to yield minimum spot growth and permit good heat dissipation.

16

There is no off-the-shelf yoke to adequately perform to the ASUPT requirements; further, much work is required to design and fabricate a suitable yoke. Estimates were made of the eventual yoke performance. Yoke linearity, i.e., the sine of the deflection angle as related to the drive current, should be to within 0.1 to 0.2 percent over the 35-degree deflection half-angle. Perpendicularity of deflection axes can be held to within 1/4 to 1/2 degree with a laminated stator yoke of the type required for the ASUPT CRT. Higher inductance yokes, on the order of 100 μh or more, give the best performance in perpendicularity.

Departure from true orthogonality can result from several causes. First and foremost, it is difficult to precisely locate the relatively large distributed winding coils in the yoke space required with sufficient precision, thus the horizontal and vertical coils will have some degree of cross-coupling. This inherent yoke error can be seriously magnified if the yoke is misaligned to the electron optic axis, which points up another reason for carefully aligning the CRT focus and deflect components. The remaining source of perpendicularity error is the incidental cross-coupling of horizontal and vertical drive signals. This points up the effectiveness of employing some purposeful cross-coupling of the deflection drivers to correct for residual error in the yoke.

Discussions were also held of the video drive requirements. Initial estimates on video drive ran from 150 to 200 volts at the high beam current required. It was further decided that in view of the high screen voltage and the developmental nature of the CRTs some arcing is probable and thus the video amplifier and other coupling circuits be designed with vacuum tube outputs.

3.2.3.2 CRT Configuration As Affected CRT Electronics Study

A sketch of the ASUPT CRT is shown in Figure 5, as dictated by the requirements of the ASUPT CRT electronics study. The shape may not correspond to the final Thomas Electronics design, which is not yet available. Total faceplate thickness will be on the order of one inch. This extremely thick faceplate is factored into the proposed alignment procedures to insure no parallax error is introduced.

3.2.3.3 Experimental CRT Data Impacting CRT Electronics

A portion of the study program carried out at Thomas Electronics generated preliminary performance data from an experimental program. Some of this preliminary data is plotted in Figure 6. There are several additional curves which can be plotted from the experimental data to more completely characterize the CRT, especially in regard to its impact on the CRT electronic system.

From the screen brightness versus beam current, Figure 7, the linearity of operation at various beam currents can be determined. At beam currents excess of about 0.5 milliamps, the screen brightness begins to depart from a linear operation. Normally, screen brightness is linearly related to beam current in regions removed from saturation, and the gamma is unity. The gamma of a process is defined by the slope of the log of the output versus the log of the input curve. Figure 7 shows the effect of phosphor saturation or a similar non-linearity at the higher beam currents.

Gamma effects in the CRT are determined by plotting the log of the screen brightness versus the log of the grid driver as in Figure 8. The gamma of the CRT is taken as the slope of the dotted line indicated. It is expected that the CRT designed for the ASUPT Program will have a higher gamma than that indicated by Figure 8. A gamma correction will be added to the video amplifier, and the exact range of gamma correction required remains to be specified.

17
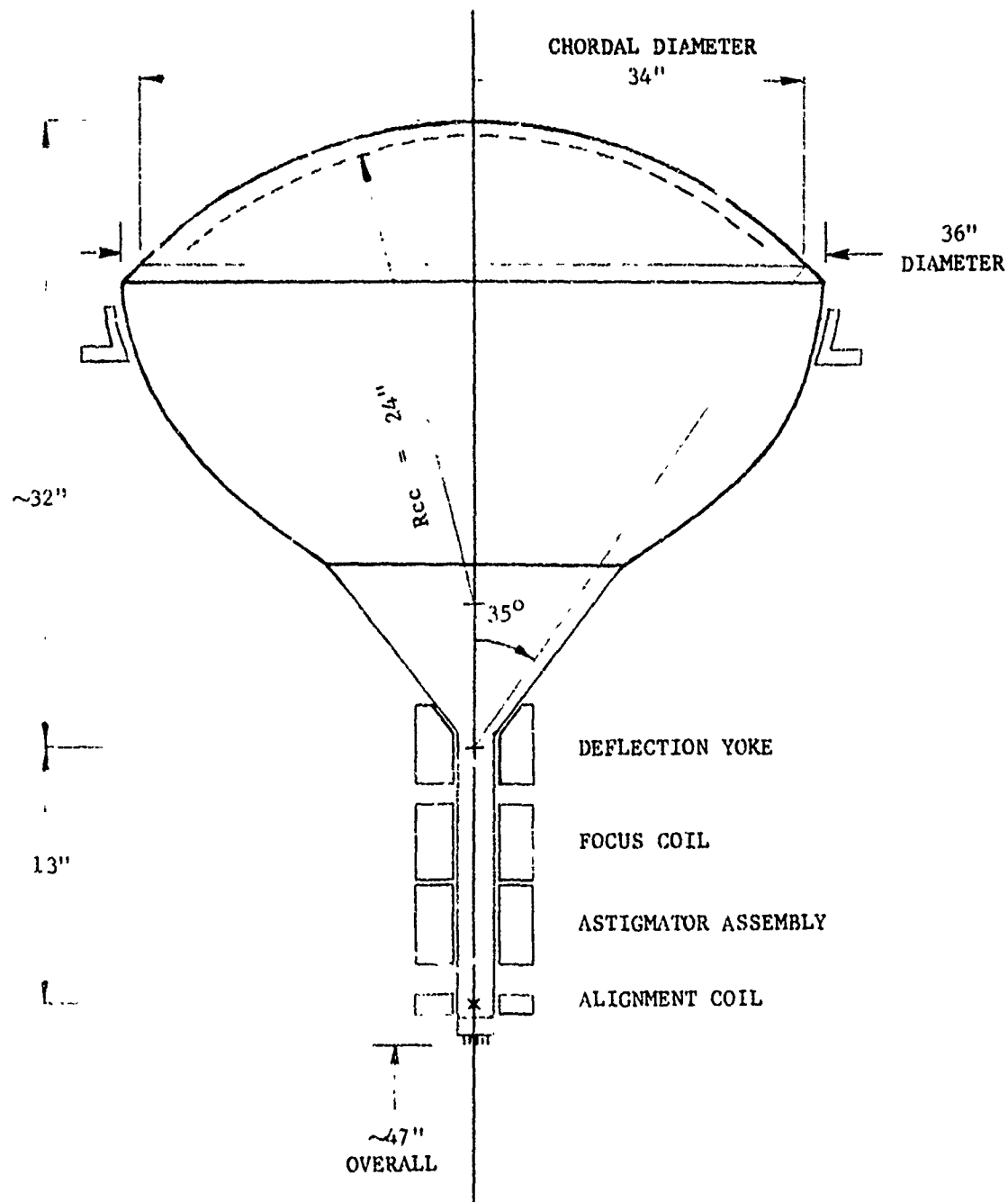
Figure 5. ASUPT CRT Configuration

18
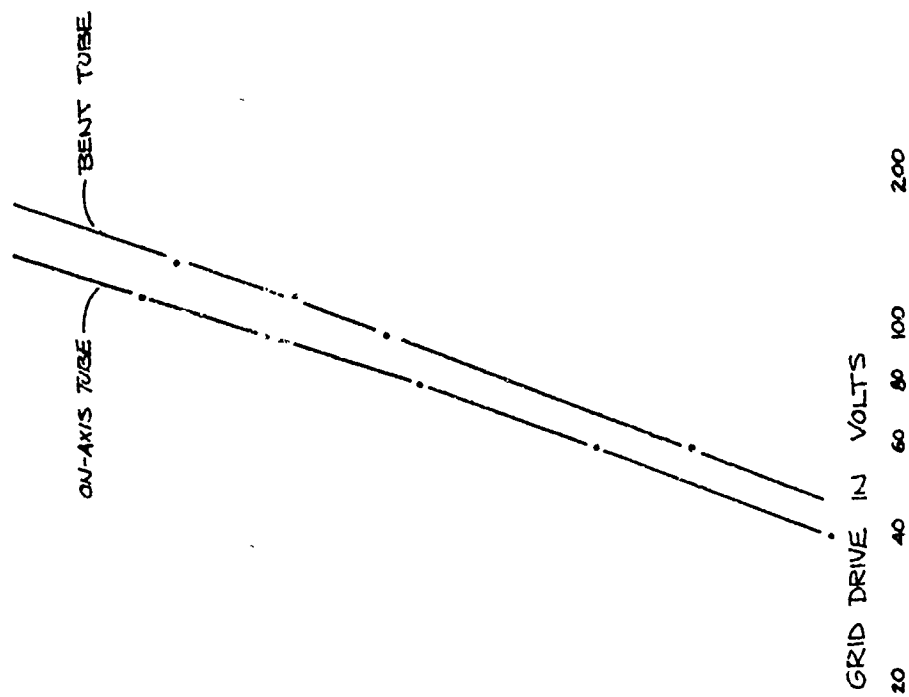
Figure 6. ASUPT CRT Grid Drive Characteristic
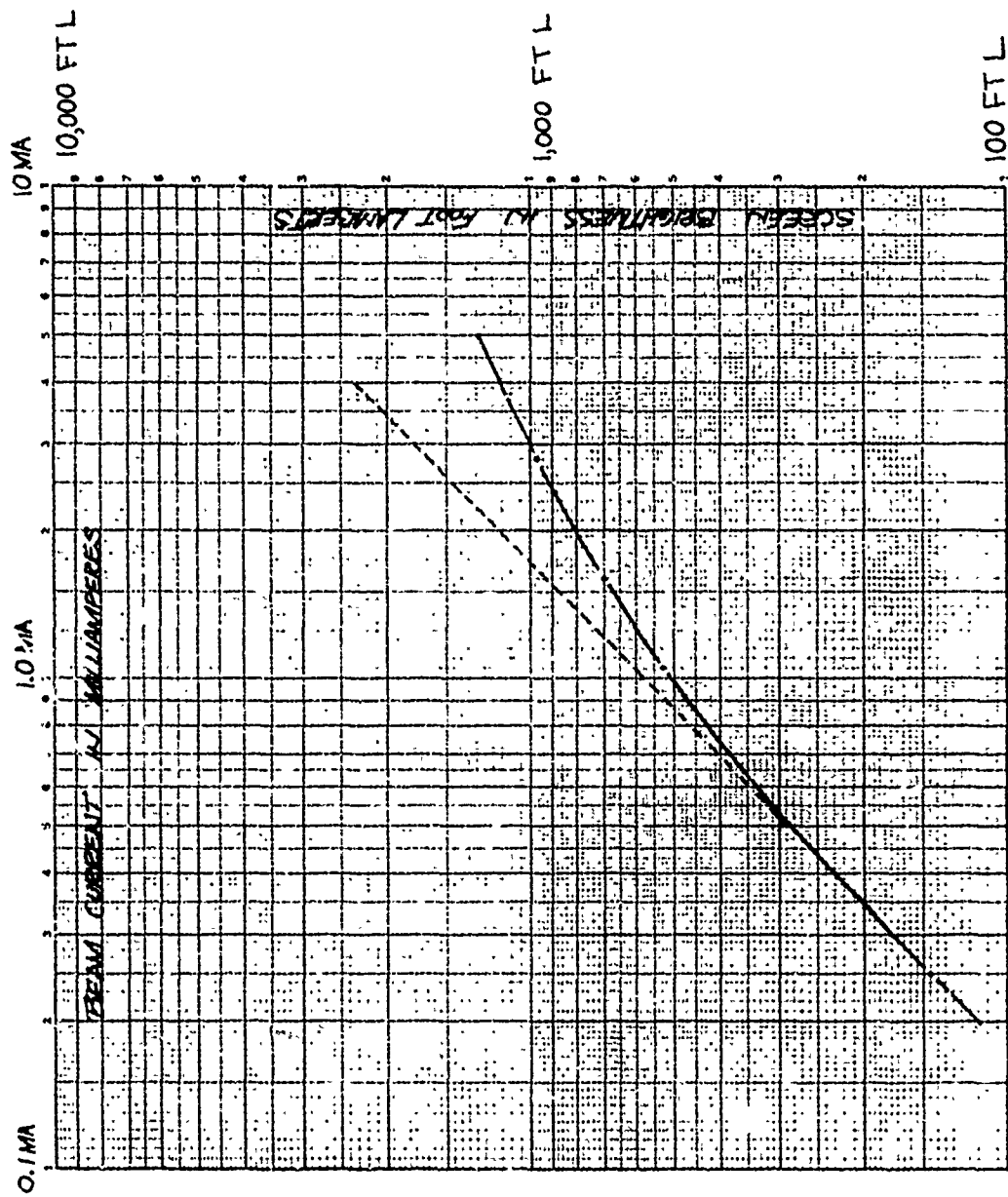
Figure 7. ASUPT CRT Screen Brightness versus Beam Current

20
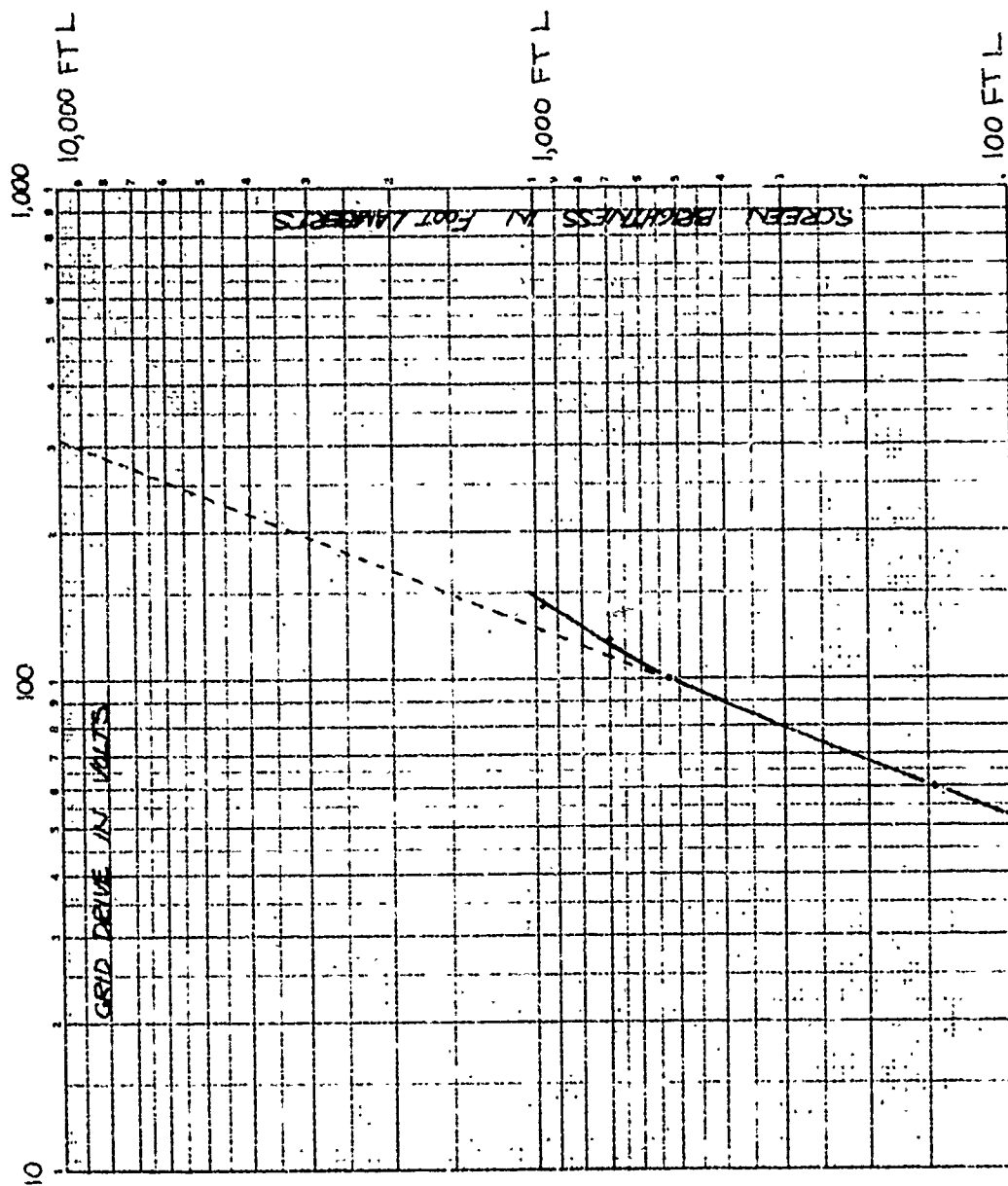
Figure 8. ASUPT CRT Screen Brightness versus Grid Drive

One further curve can be derived from data on the experimental CRT, spot size variations versus beam current. This is used to determine the spot size at the raster edge with shading corrections applied. This data is indicated by Figure 9. The data is specific to a beam velocity of 600,000 inches per second.

The major question which remains centers about obtaining sufficient screen brightness from the CRT. A simple method to accurately estimate the screen brightness involves finding the useful screen area, determining the radiated light flux by multiplying the average beam power by the phosphor power efficiency factor, which for P-20 is approximately 40 lumens/watt. Though the useful raster area on the spherical CRT is complex, it can be simply found by looking to Figure 3 for the virtual object surface and noting this area is comprised of the area bounded by nominal field of view and the surrounding strip out to the limits of maximum field-of-view. The inner area is 1/12 the surface area of the virtual object sphere. Raster area for nominal field-of-view is:

$$A = \frac{4r^2}{12} = \frac{r^2}{3} = 5.5 \text{ square feet}$$

As a trial calculation, assume a 35 kv, 4 milliamp beam was continuously scanned over the rectangular area in Figure 3. Also assuming compatible TV blanking proportions, the active scan time for the rectangular raster is 0.78 frame time and the ratio of the pentagonal area to the rectangular area is 0.692. Thus due to the duty cycle factors identified, the actual screen power on the useful raster is 75.6 watts which yields a screen brightness of 555 footlamberts. Using typical on-axis window transmission of the Farrand window to be 0.75 percent, the observed peak display brightness is 4.16 footlamberts. The peak beam current must be increased to 5.7 milliamps or the pancake window transmission must be improved to meet the ASUPT requirements of 6 footlamberts highlight brightness.

3.2.4   CRT RASTER GEOMETRY

3.2.4.1   General

To interface with the Farrand virtual image optical system places some rather unusual constraints on the CRT system. Since the optical system places the CRT screen on the virtual object surface it is as though the observer is viewing the computed raster from within the CRT. Thus a raster of straight lines on the computed plane will be curvilinear on the CRT screen. A straight scan line on the computed plane must be represented by a line on the CRT screen which is the intersection of the spherical CRT screen surface and the plane passing through both the scan line on the computed plane and the virtual eye point. Thus, each scan line on the CRT screen is a great circle.

Figure 10 gives the plane geometry representation of this situation. Here a grid of 10 uniform spaces is formed as a uniform raster on the computed plane. The raster distortion required on the CRT screen is shown by points on the circle at the intersections of lines drawn from computer raster line location and the eye point. The intervals between scan lines on the CRT diminish as the angle ϕ increases. The sweep waveform corrections to obtain this distortion are, therefore, of the same form as the waveform corrections used in a flatface CRT system employing an electromagnetically deflected beam. A simple analysis yields a relation between the computed plane and the CRT summarized in Figure 10.

22
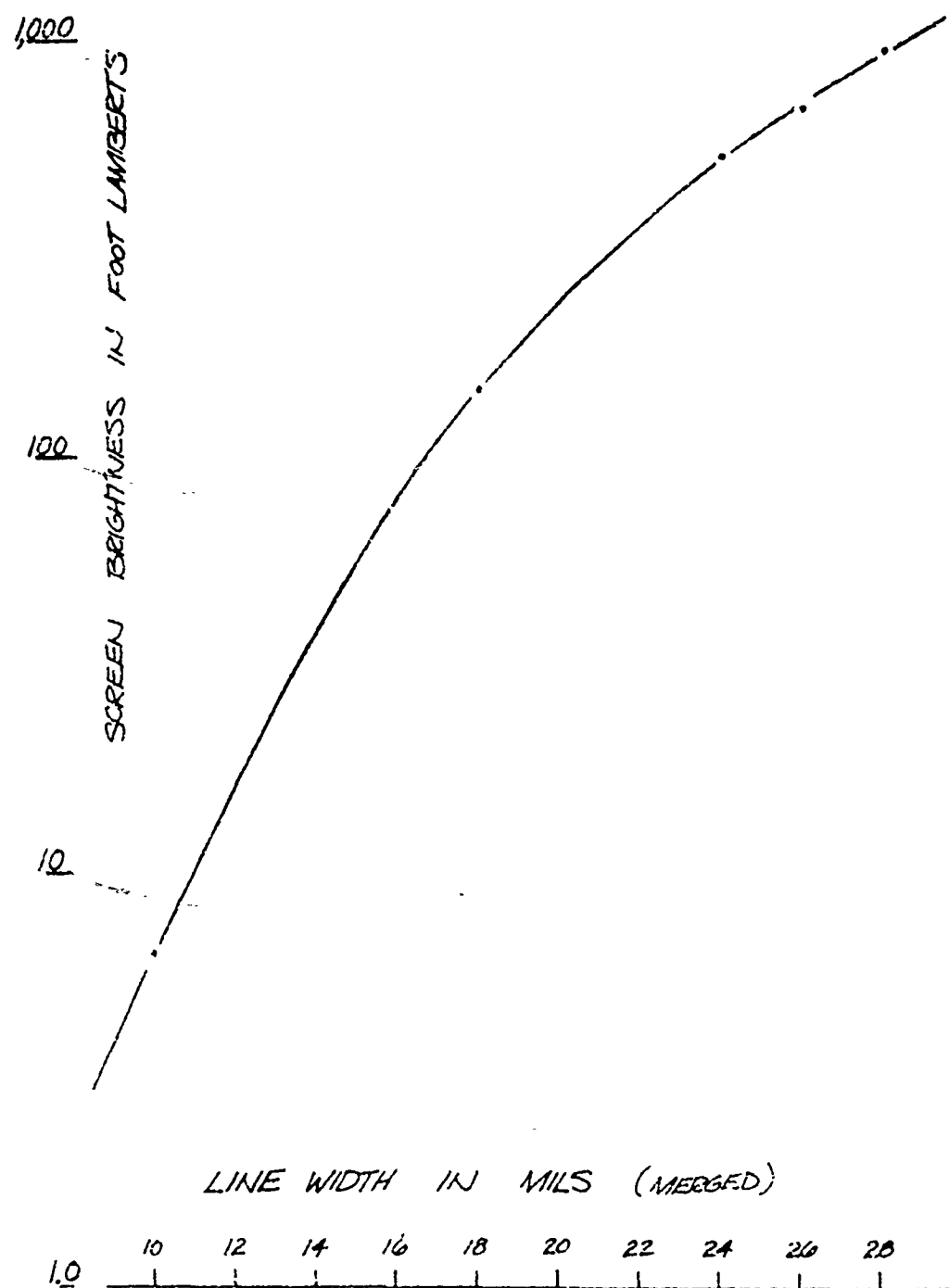
Figure 9. ASUPT CRT Screen Brightness versus Line Width

23
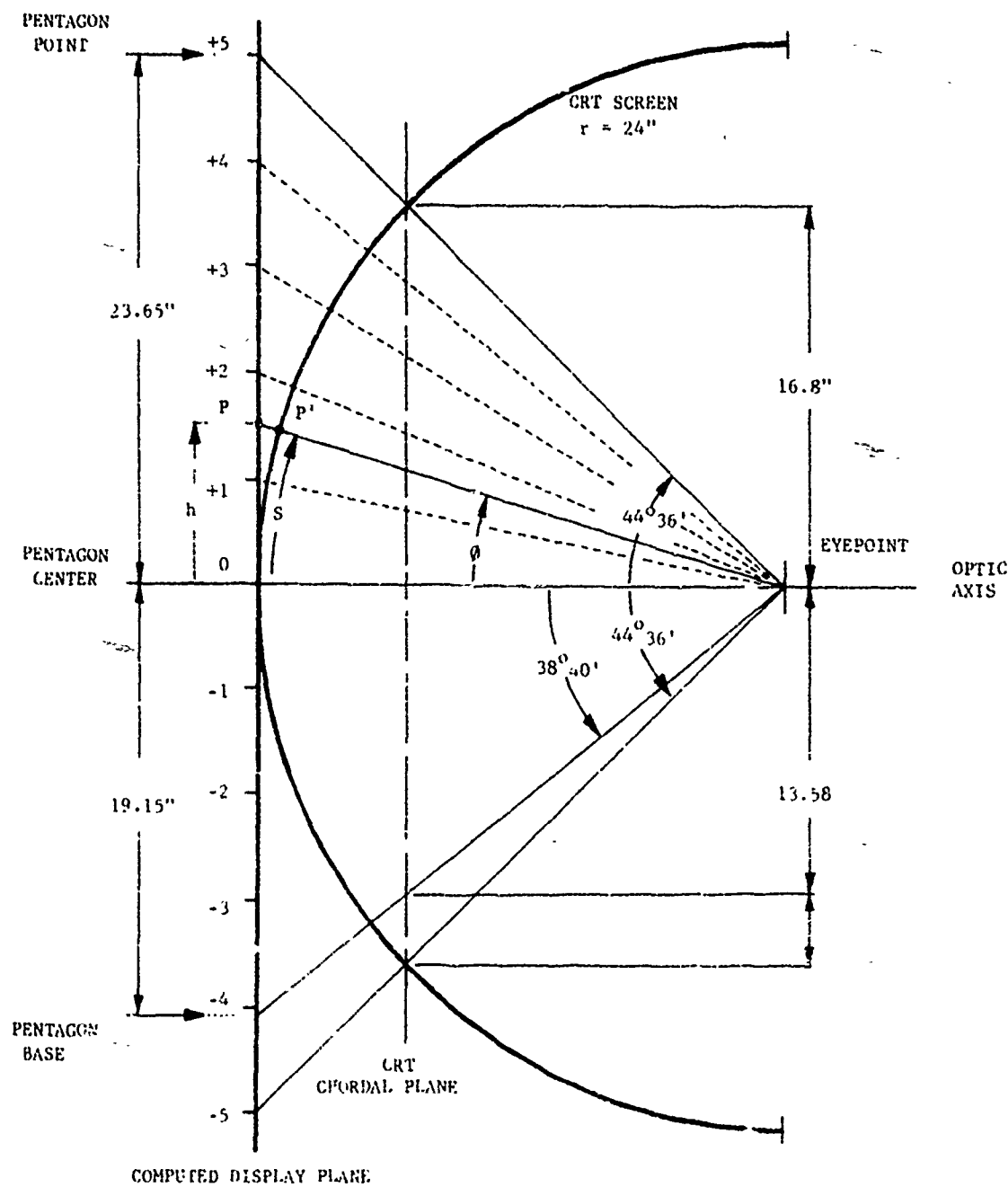
Figure 10   Plane Geometry Representation of the Computed Display
Plane—CRT Screen

For 1000 scan lines, the on-axis CRT line spacing is

$$r_c = \frac{h_b + h_p}{1,000} = 42.8 \text{ mils}$$

Note the above calculation and much of what follows is based on a raster with scan lines parallel to the pentagon base and all 1,000 scans between pentagon point and base. The number of scan lines above and below the axis is in proportion to the center of pentagon base and point (Figure 11).

An accurate estimate of scan velocity at the CRT center may be made by determining the horizontal extent of the raster in the computed plane. This quantity is shown in Figure 11 as 45 inches. The active horizontal scan time is approximately 26.5 μsec, so CRT center scan velocity is 1.7×10^6 inches/second. From Figure 10, a two dimensional analysis quantifies the distortion required on the CRT raster.

The conclusion of this analysis is that the raster lines are getting closer as a function of the viewing angle, ϕ, to the point that at the pentagon point ($\phi \approx 45°$) the scan line spacing must be half that of the center. With a center spot size of 42.8 mils as calculated above, the spot must be reduced about half or 21.4 mils at the pentagon point. This $\cos^2\phi$ compression of the raster will result in a need for a corresponding dynamic brightness correction to maintain a uniform brightness over the CRT screen which is essential to maintain uniform brightness of the final image. A suitable shading correction varying as an area compression must be provided.

3.2.4.2 CRT Raster Shading Corrections and Resolution Element

From the 3D view of the geometric situation of Figure 12(a) the solid angle representation shown in Figure 12(b) was constructed. Analysis yields a relation between the elemental areas on the computed plane and the spherical surface. So then

$$A_F = \frac{A_s}{\cos^3\phi}$$

Therefore, while the incremental area over the computed plane is uniform, the corresponding incremental area must vary as the $\cos^3\phi$ function of the field angle ϕ.

Figure 13 shows the complete functional variation of the resolution element over the CRT raster. Scan line spacing is denoted by d and resolution element spacing along the scan by r. The center or on-axis resolution element on the CRT is denoted by $(r_o \times d_c)$.

Since the exact form of the CRT raster is crucial to successful operation of the ASUPT visual system, a scale model was built to clearly demonstrate the form of the ASUPT CRT raster. Figure 14 shows two views of this completed CRT raster mode. The model verifies the correctness of the analytical treatment given above. The resolution element area varies as the $\cos^3\phi$ function, but Figure 13 shows the resolution element is not square. The resolution elements will be smaller in the radial dimension than they are in the transverse dimension and vary as shown in Figure 15.

One can further examine Figure 13 and the photographs of the raster model in Figure 14 and note that the electron beam scan velocity is not linear. Since the beam must scan each grid in equal time for a uniform raster in the computed plane, the beam will slow down toward the raster edges. The maximum scan velocity occurs on axis and the

25
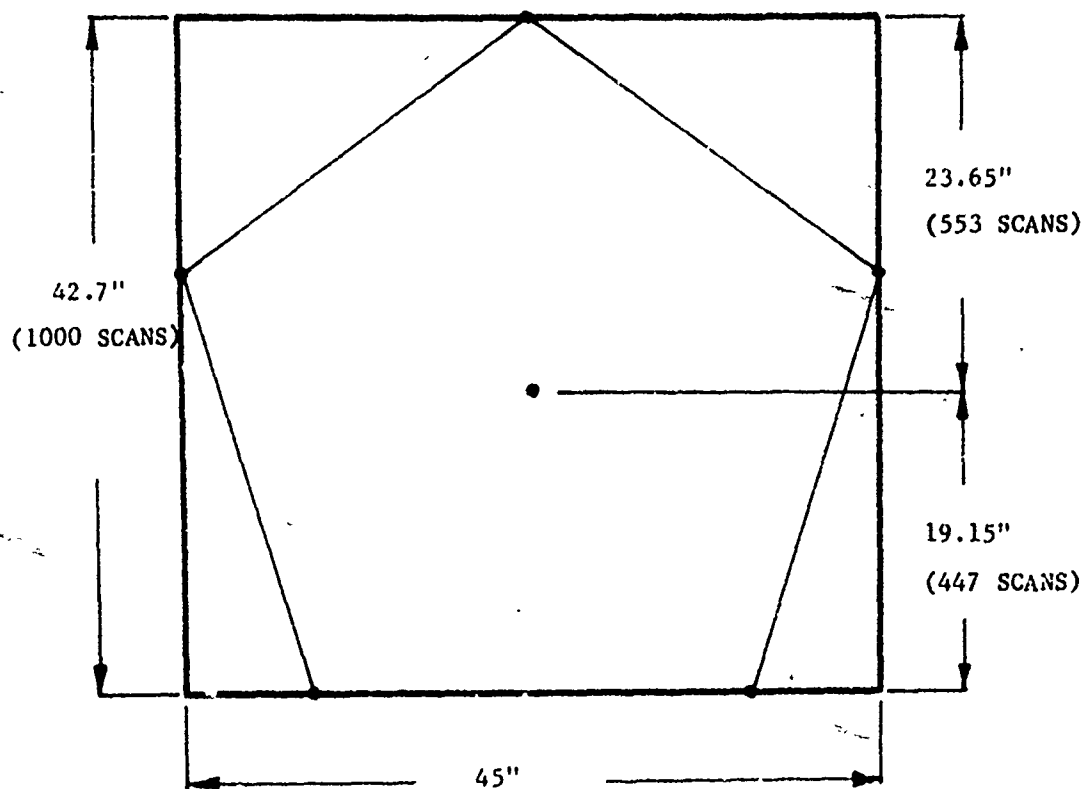
Figure 11. Dimensions of the Computed Plane
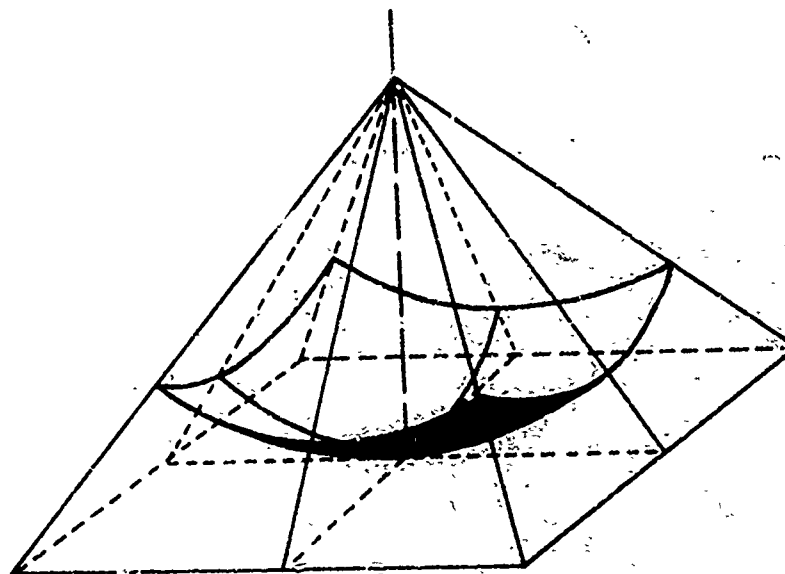
(a) 3D View of CRT Screen and Computed Display Plane
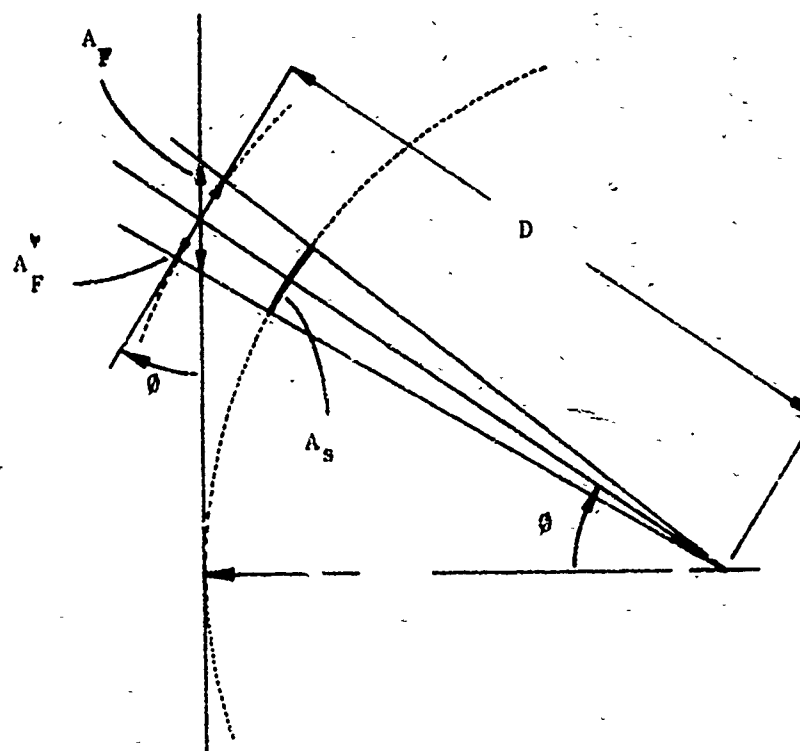
(a) Solid Angle Representation of CRT—Display Plane Geometry

Figure 12. 3D Representation of Computed Display Plane—CRT Screen

27
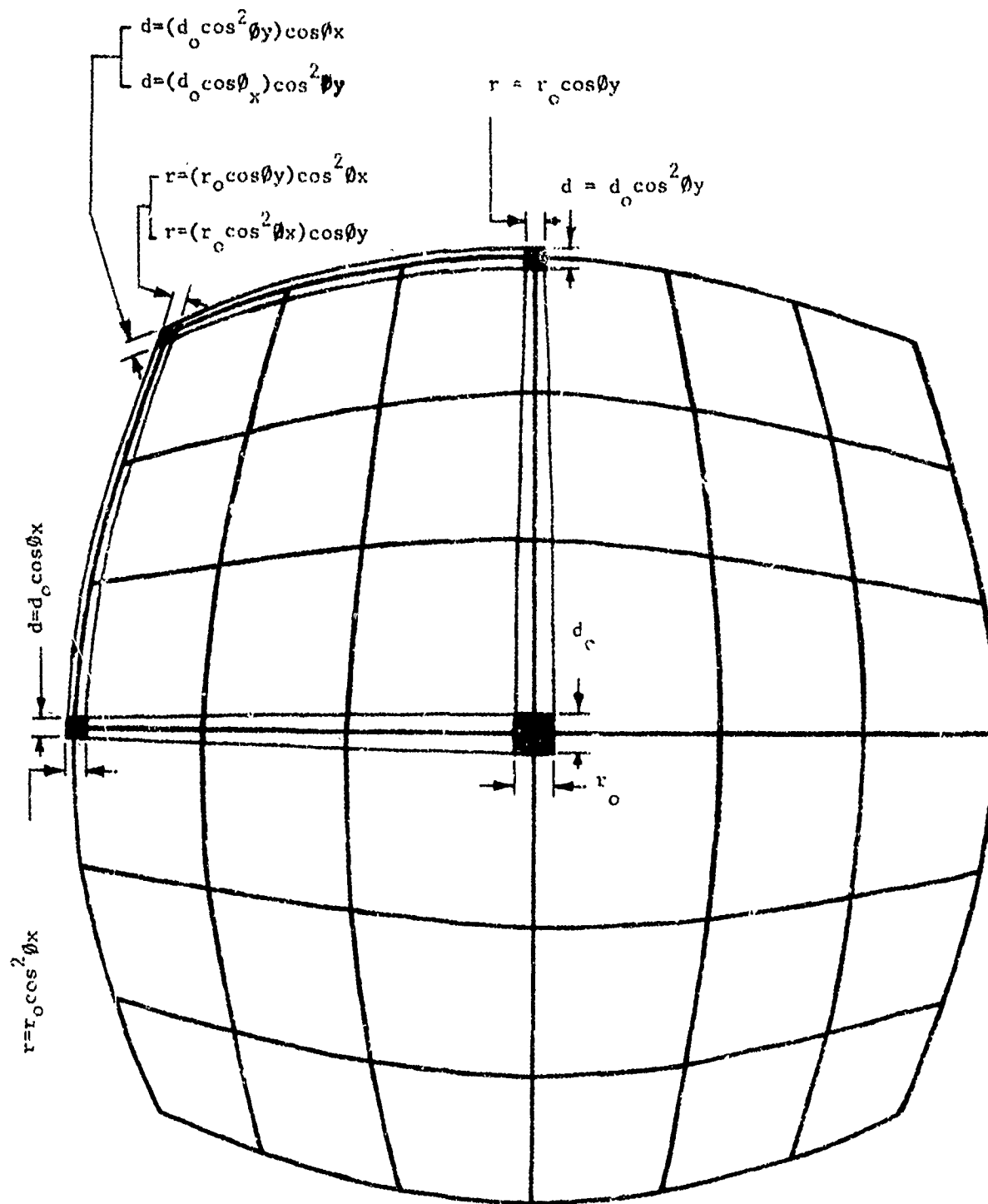
Figure 13. Geometric Determination of Resolution Element at Any Point on the CRT Raster
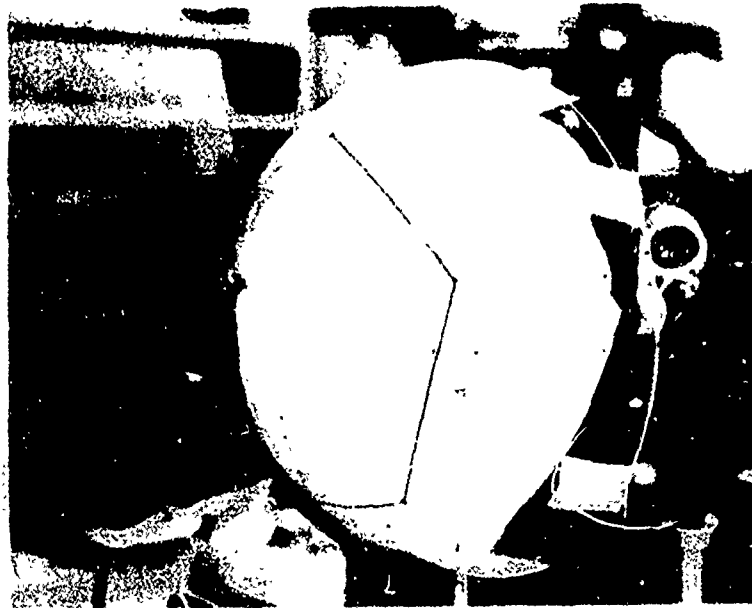
(a) Oblique View (45°) of Raster Model
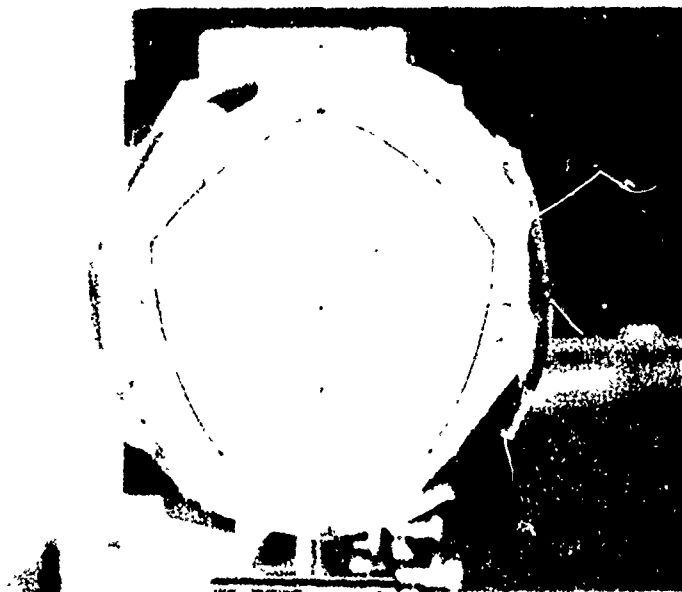
(b) On-Axis View of Raster Model

Figure 14. On-A .: and Oblique View of ASUPT CRT Raster Model

29
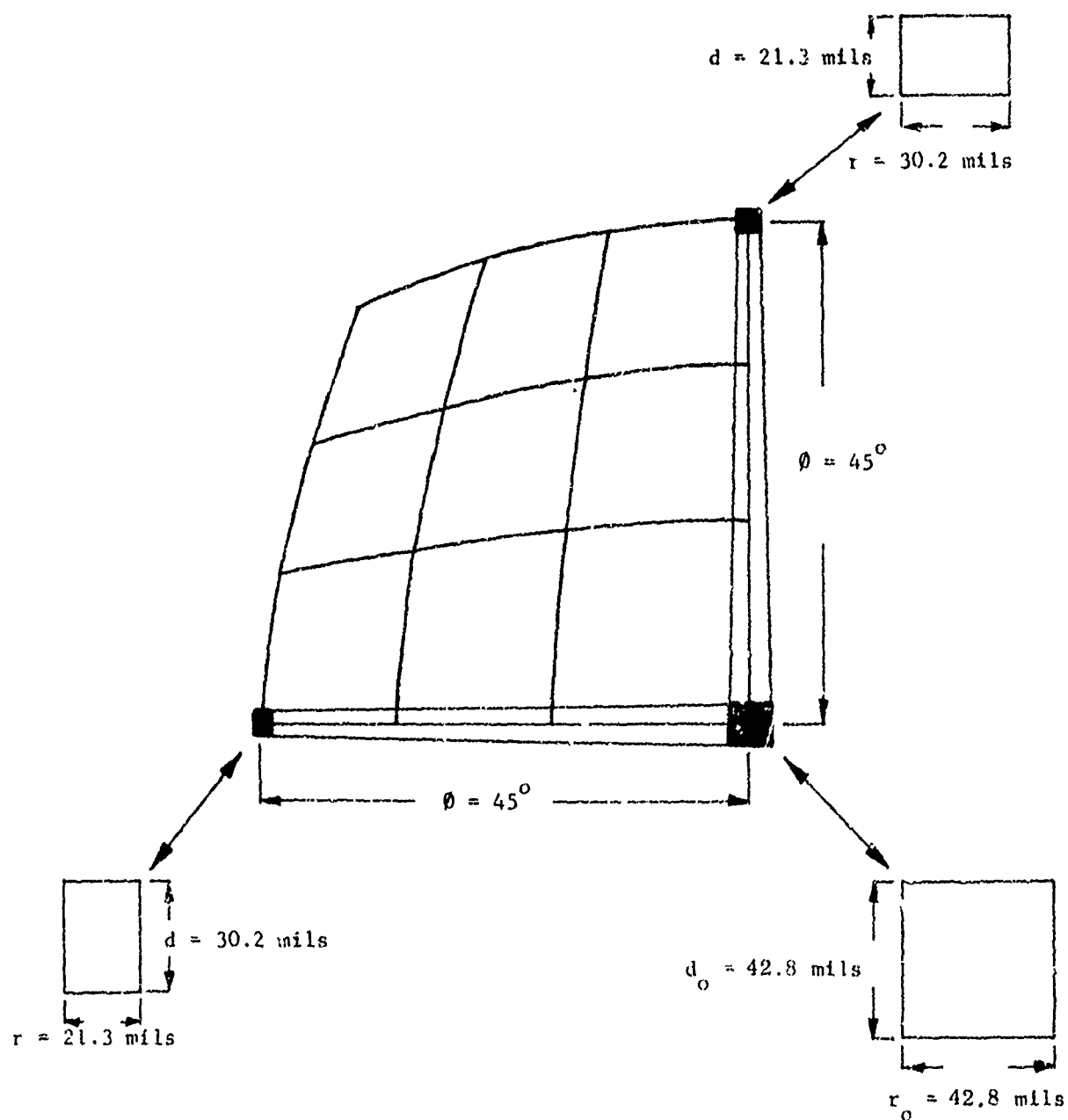
Figure 15. Inherent Astigmatism in the ASUPT CRT Raster

minimum velocity occurs at the corners. Though screen brightness increases with decreased scan velocity, this should not be accounted for by an additional shading correction. The $\cos^3\phi$ shading correction already accounts for the nonlinear scan velocity by virtue of the mapping from the computed plane to the CRT.

To prove the correctness of the ASUPT CRT raster, an experimental reconstruction of the computed display plane using the ASUPT CRT raster model was made on an optical bench. The glass hemishpere (Figure 14) was mounted on an optical bench holder and a microscope objective was positioned at the center. A laser was used as a light source to cast a shadow of the raster on a flat plane. Observation of the computed display plane image showed it to be a uniform grid in spite of the "hand-built" raster model. A record was made of this image by exposing an 8 inch by 10 inch high resolution photographic plate in the tangent plane. A print of this appears as Figure 16. The reconstructed computed display plane proves the validity of the ASUPT CRT raster mode.

3.2.4.3   Resolution Performance Estimate

Resolution requirements at any point on the raster are well defined by the expressions of Figure 13. To show this situation better, a plot will be made of the resolution element size requirements, both in the transverse and radial directions, along with the expected spot size including effects of the $\cos^3\phi$ shading correction. First it is necessary to determine the spot size with the shading correction applied. Figure 17 shows the beam current versus line width for both the on-axis gun test and the bent-neck CRT test. As shown, the bent-neck CRT test yielded a smaller line width than the on-axis test at higher beam currents. This is not normally the case. Likewise the bent-neck CRT test does not evidence the markedly increased spot growth at the higher beam currents. In view of these departures from expected behavior an on-axis spot size of 39 mils was selected for an expected spot dimension at high beam current (i.e. about 4 milliamps). The actual spot size to yield a cleanly resolved raster will be somewhat in excess of the merged line data figures due to rather broad skirts on the electron spot.

To generate a curve for spot size with $\cos^3\phi$ shading correction, the beam current for the on-axis spot is reduced by $\cos^3\phi$ at each value of field angle. This yields a reduced current which is used as an entry to data such as shown in Figure 17 to determine a corrected spot size at each particular field angle. Complete CRT test data of spot size versus beam current for a range of field angles is not yet available, thus the bent gun test data was used. Since the $\cos^3\phi$ function causes a 4/1 reduction of beam current at $\phi = 50$ degrees, the corrected beam current near the raster edge is about 1 milliamp. Due to the very small change of bent gun spot size with beam current the effects of shading correction on spot size are almost negligible. Likewise the effect of Farrand window shading correction is negligible on resolution as shown in Figure 18. Figure 18 shows the ASUPT raster requirements as a band between a $\cos\phi$ variation for the transverse spot dimension and a $\cos^2\phi$ variation for the radial spot size requirement. In actual practice the 30-mil on-axis spot is a 30-mil merged line spacing for limiting resolution. An equivalent spot size will be a higher figure, but this must be determined from experimental data since it is influenced by many factors. As shown by Figure 18, the actual spot could be larger, however, the on-axis resolution was obtained by dividing the available computed display plane by 1000. If the spot were exactly 42.8 mils as calculated, the resulting contrast is not high due to skirts on the electron spot. In conclusion, the data thus far on the experimental CRTs is encouraging, but not conclusive.
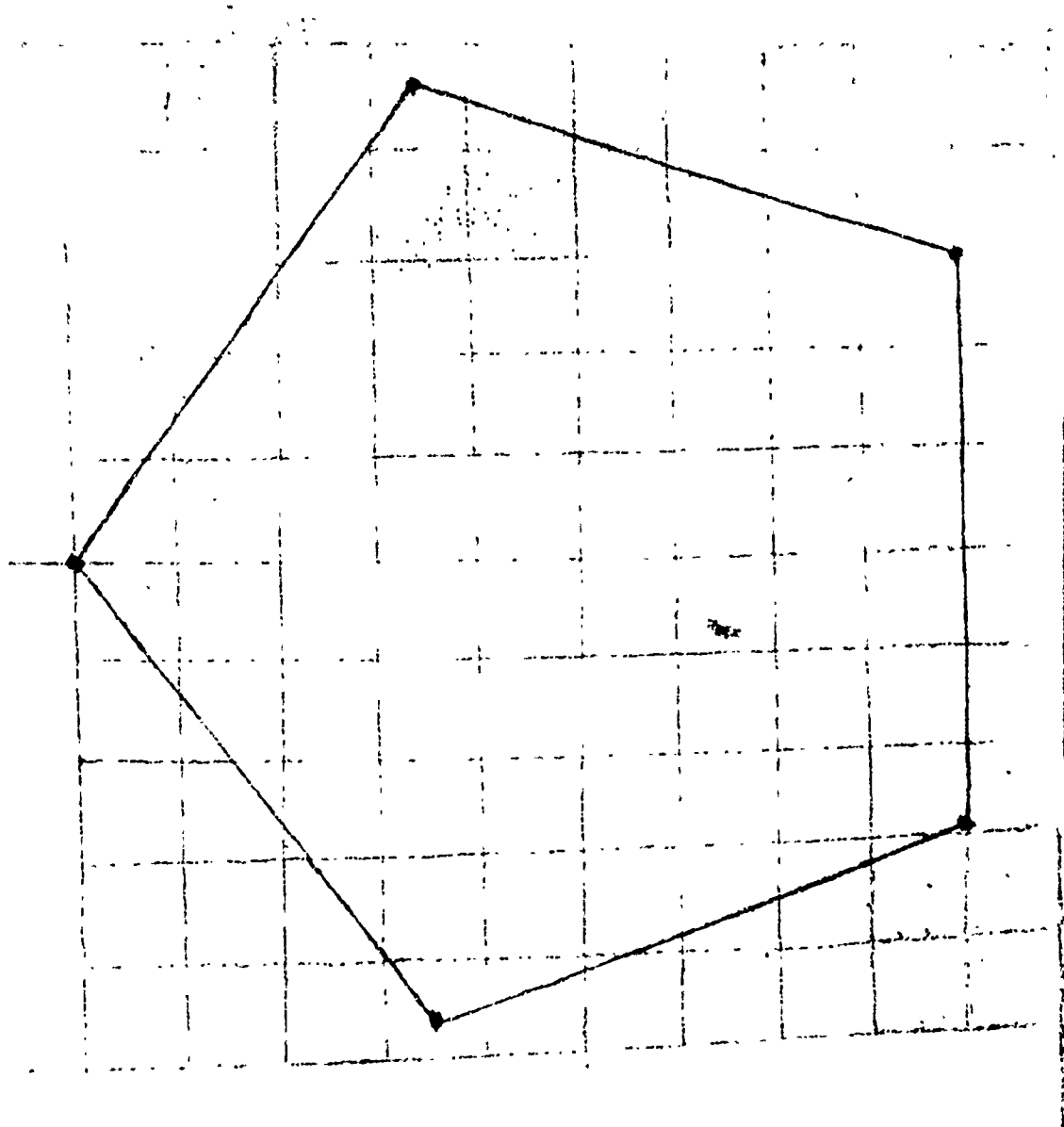
Figure 16. Reconstructed View of ASUPT CRT Raster Model at the Tangent Plane

10 MA

1.0 MA

0.1 MA

BEAM CURRENT IN MILLIAMPERES

ON-AXIS TEST

BENT GUN TEST
(35° DEFLECTION)

LINE WIDTH IN MILS (MERGED TEST WITH BENT TUBE)

10 12 14 16 18 20 22 24 26 28 30 32 34 36 38

Figure 11. SHPT CRT Beam Current versus Line Width
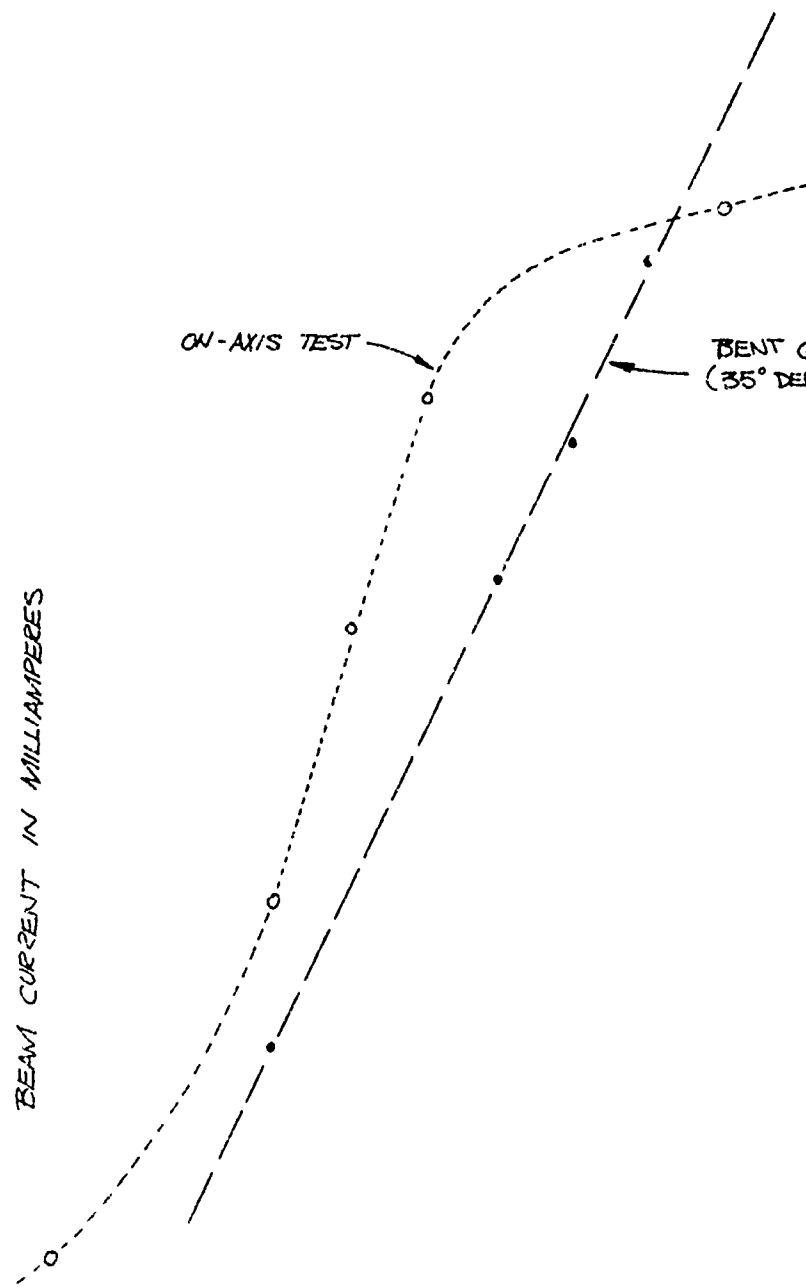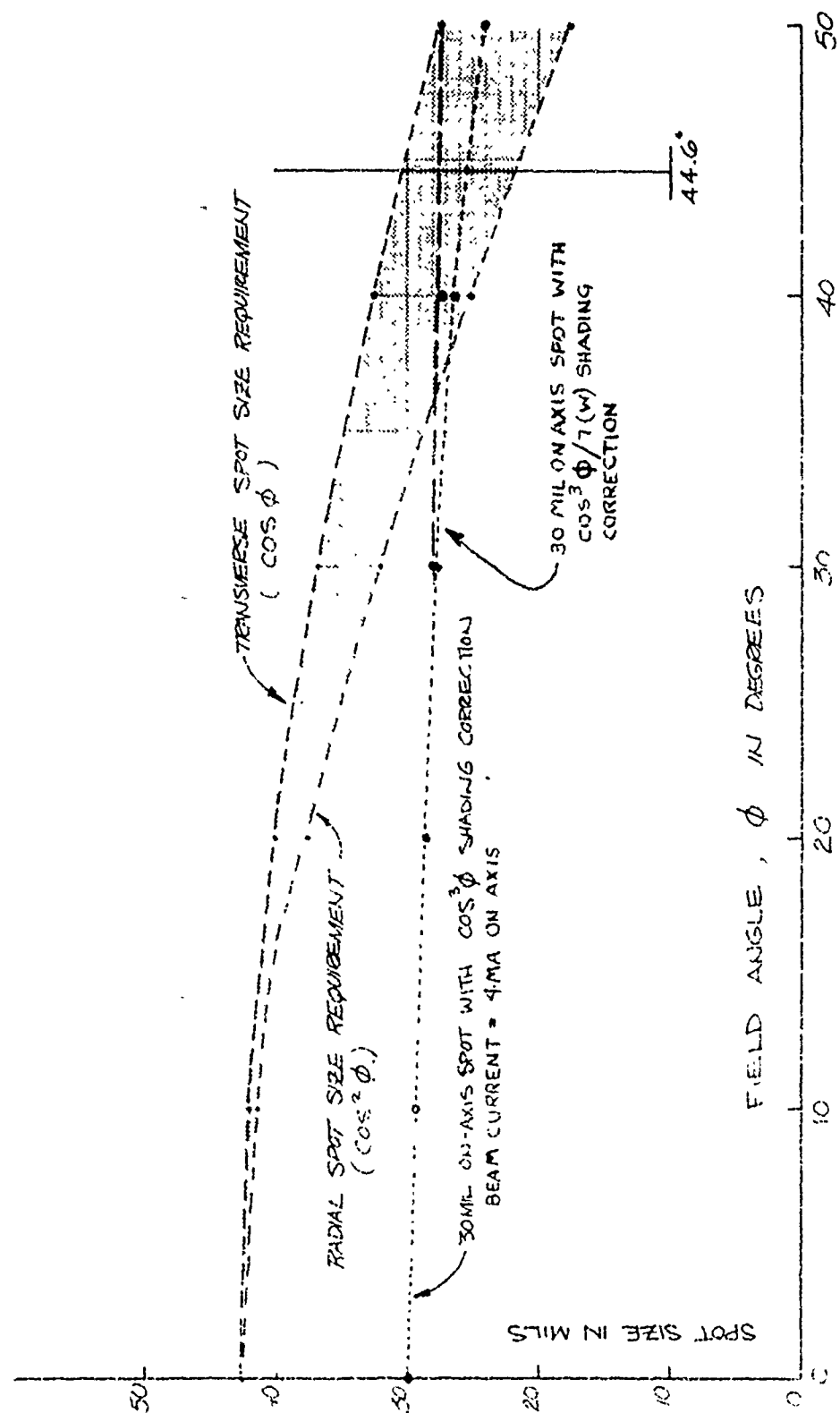
Figure 18. ASUPT CRT Resolution Requirements and Experimental Performance (Corrected)

34

3.2.5   CRT ELECTRONICS SYSTEM—BLOCK DIAGRAM

3.2.5.1   General

This paragraph of the report is concerned with the formulation of a basic feasible CRT electronics system to permit the identification of the functional interfaces between the electronics and the CRT. Figure 19 gives the block diagram for a basic feasible CRT electronics system. This system of blocks is at this point only schematic and does not necessarily represent the exact form of the final CRT electronics system. Figure 19 is the result of studying the ASUPT visual display system requirements and generating an electronic system which can provide all the necessary corrections, signals, voltages, or functional control.

3.2.5.2   Focus and Deflect Components

Before examining the CRT electronics system in detail, it is instructive to discuss the form specified for the focus and deflect components. Figure 20 shows a 1/2 scale view of the focus and deflect components with an indication of their function in controlling the electron beam. A beam alignment coil is specified to insure maximum beam output from the emission system with a symmetrically defined beam. A beam alignment coil is a small two axis deflection coil placed over the cathode lens region to align the beam with the axis of the cathode lens.

Next in line is the astigmator assembly. This assembly insures the beam is symmetric and has a circular cross-section before entering the focus and deflect coils. Astigmatism corrections are applied on both a static and a dynamic basis. Static astigmatism corrections correct the undeflected spot to a circular shape and the dynamic astigmatism corrections maintain a circular spot shape point-by-point as the beam is scanned across the screen. The astigmator coil consists of two sets of four coils each which establish a magnetic field which can elliptically stretch the beam in each of two normal axes. If the astigmator coils are to produce a spot stretch without beam deflection, the beam must enter the astigmator centered and aligned with the electron optic axis. Thus, the requirement for a separated two coil centering system.

A magnetic focus coil is located just past the astigmator assembly. This component is employed to focus the beam to a small spot at the screen. The focus function as indicated in the block diagram of Figure 19 consists of three separate functions. Static focus, F_s, is explained above; video focus, F_v, is a focus correction which must be added to account for the change in cross-over, or electron optical object, position with the exceedingly large grid drives of 150 volts or more encountered in the ASUPT CRT. Dynamic focus, DF, corrects the electron beam on a dynamic basis while scanning the raster for the point-by-point change in the focus coil to screen distance. If the deflection center were coincident with the screen radius of curvature the distance from the focus coil to the screen would remain constant and no dynamic focus function would be required.

The deflection yoke is the last component to operate on the beam. Corrected horizontal and vertical drive signals are sent to the yoke to cause the electron beam to scan out the proper raster for the ASUPT visual system. Due to the complex nature of the optical display system the drive applied to each yoke axis is functionally cross-coupled.
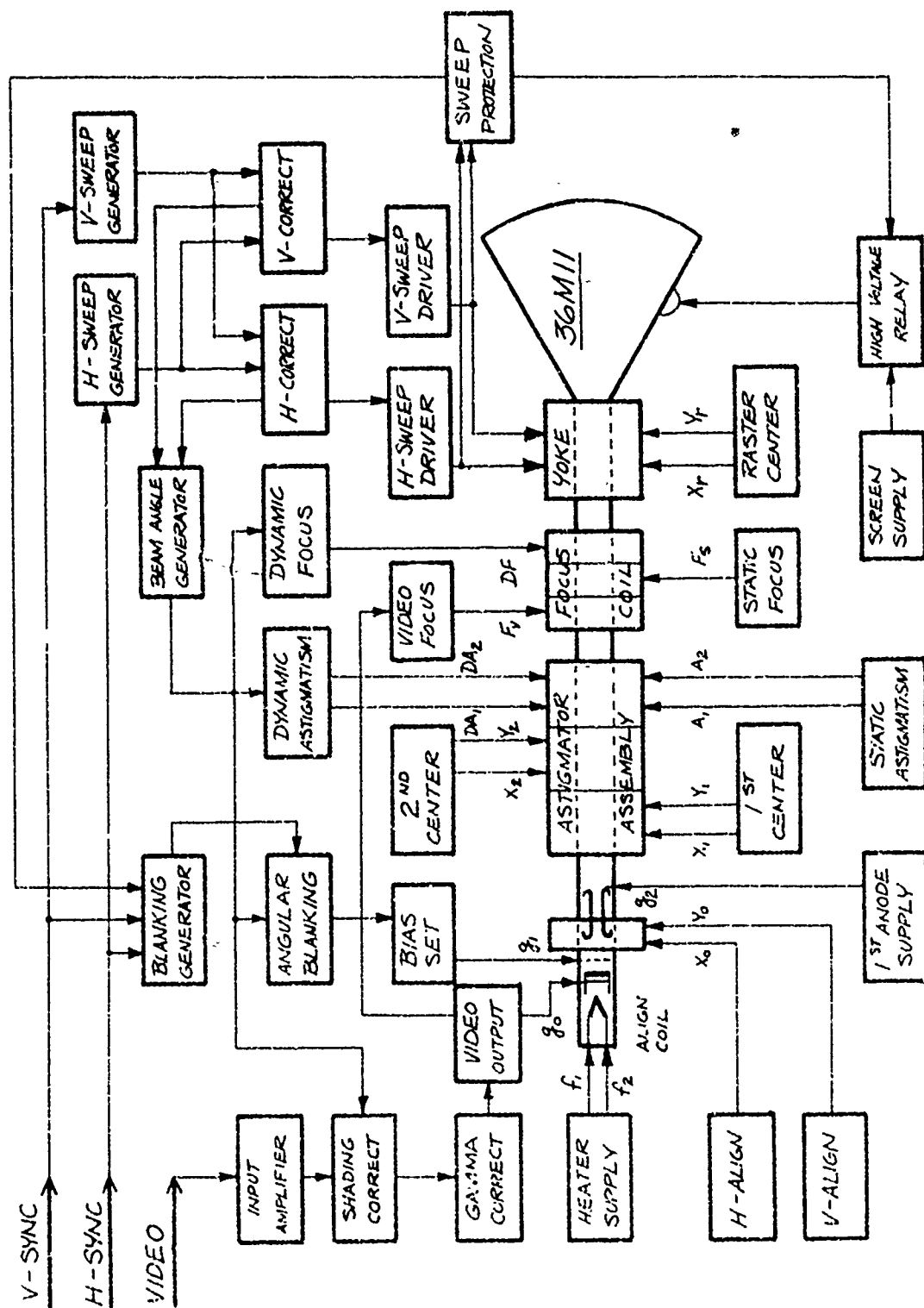
Figure 19. Block Diagram—CRT Electronics System (Corrected)
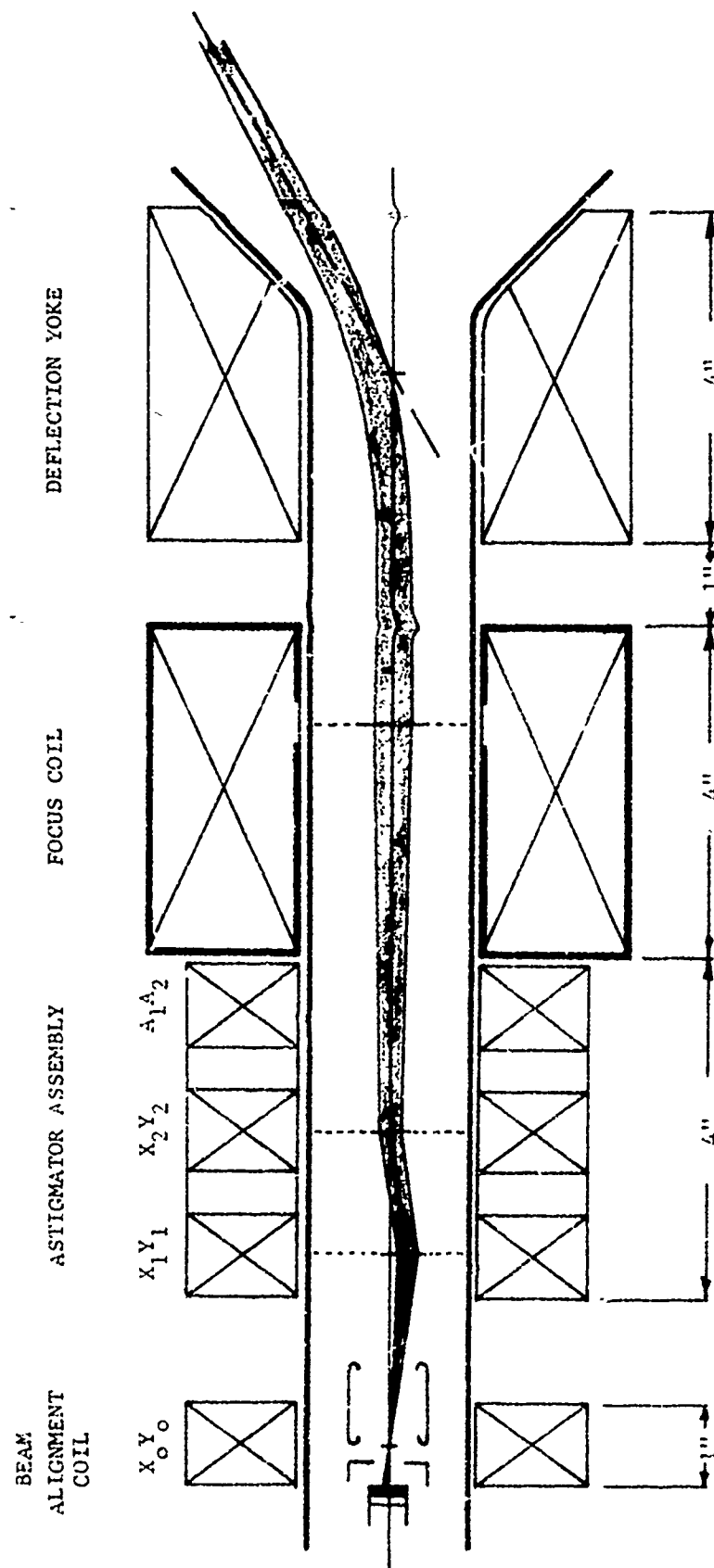
Figure 20. ASUPT CRT Focus and Deflection Components

SCALE, 1/2

37

3.2.5.3 CRT Electronic Functional Circuits

The CRT electronics system obtains three inputs from image generation computer system, namely H-sync, V-sync, and video. As discussed in detail later, there may be merit in considering the system interface where the image generation computer sends an H and V ramp or some other accurate indication of the instantaneous expected position for the electron beam.

Video from the image generation computer is first sent to an input amplifier, which provides suitable buffering and converts from the differential form convenient for signal transmission to that required in the shading correction block. A number of shading corrections are required. The proper ASUPT CRT raster requires a strong shading correction as a function of position on the raster. Thus the field angle is generated from the raster position and sent to the video chain to effect this correction. Other corrections are required for Farrand window transmission variations and incidental shading errors. Once the video signal is suitably corrected it is sent to the gamma correct circuit which suitably distorts the signal in a nonlinear fashion to force the screen brightness to be linearly related to the signal input to the gamma correct circuit. Gamma correction, as well as shading correction, are at low signal levels and the video output driver is employed to raise the signal level to drive the CRT. As shown in Figure 19, the electronics are arranged to provide cathode instead of grid drive. This has a number of merits which are discussed later with the video amplifier. A sample of the video output is sent to the video, focus correction block. This correction adjusts the focus fields for the cross-over shift at high video drive.

Blanking is applied to the grid, or the g, electrode. Beam blanking is applied to provide a number of functions. The normal horizontal and vertical retrace blanking functions are generated from the H-sync and V-sync signals. An additional blanking waveform is generated from the beam angle to blank the beam outside the useful pentagonal define of the raster. This blanking function can appreciably reduce the average beam current. A third blanking function is that of sweep protection. Inputs from the H-sweep and V-sweep drives are sent to the sweep protection block. Loss of sweep or even reduction of sweep drive below some preset value will automatically blank the beam.

This function is critically important, for if the beam were permitted to operate at high beam power, while undeflected, the phosphor and even the tube would be destroyed. As an additional precaution, if the CRT is operated without sweep drive for a preset time period, then the sweep protection block sends a signal to the high voltage relay, shown in Figure 19, and screen voltage is removed from the CRT.

A horizontal and vertical sweep, or sawtooth waveforms, are either generated directly in the CRT electronics system from H- and V-sync or sent from the image generation computer to provide a spatial reference for the video. These signals indicate the position of the current video element and are consequently employed to provide the proper sweep corrections to force the electron beam to trace the computation plane mapped onto the CRT screen. Due to the cross-coupling, both H-sweep and V-sweep waveforms are required to provide the corrected input to both the H-sweep driver and the V-sweep driver. The sweep drivers linearly convert the corrected input voltage signal to a deflection yoke current drive. Additional corrections are provided to overcome any departures in the deflection yoke from exact linearity or perpendicularity of deflection axes. Raster position is controlled with raster centering, designated X_r, Y_r in Figure 19. Normally raster position is effected by providing an offset in the DC value of the sweep current waveform. In the ASUPT CRT there are some binding reasons for keeping the raster position function separate from the beam deflection.

38

First, due to choice of raster center to optical channel center a fixed offset is required. Second, the sweep driver circuits will be a stringent design with high peak to peak and large flyback voltages, thus it is wise to simplify the design by specifying a separate raster position function.

This section has developed a basic feasible CRT electronics system which can generally meet the requirements of the ASUPT visual system. Later sections of this report further specify the ASUPT CRT electronics system.

3.3   PERFORMANCE SPECIFICATION—CRT ELECTRONICS

3.3.1   FUNCTIONAL INTERFACES/OPERATING PARAMETERS

A series of steps were employed to evolve the Interface Flow Chart. First the general considerations shown in Figure 21 were used with the detailed data of Subsection 3.2 to develop the Interface Block Diagram of Figure 22. This resulted in the CRT Electronics System Interface Flow Chart, The functional interfaces are listed below with a brief description for each. These interfaces are shown in the Interface Flow Chart, Figure 23.

3.3.1.1   Interface List

3.3.1.1.1   CRT Electronics/Image Generator Computer

3.3.1.1.1.1   Video—The video signal is computed by the Image Generator (IG) and sent to the CRT electronics from the video processor. It is corrected and distributed in the CRT electronics where all the required signals are generated for controlling the CRT brightness, shading, gamma, and other pertinent parameters. It is a standardized non-composite signal.

3.3.1.1.1.2   H-Sync (Separate Sync)—The H-sync signal received from the image generator provides a reference for the generation of H-timing pulses, ramps, and correction functions used in the CRT electronics. It is a standardized sync signal.

3.3.1.1.1.3   V-Sync (Separate Sync)—The V-sync signal also provides a reference for V-timing pulses, ramps, and other correction functions required by the CRT electronics. It is a standardized sync signal.

3.3.1.1.1.4   H-Ramp—The H-ramp generated by the image generator is corrected and distributed by the CRT electronics and amplified to produce the required H-sweep input to the CRT deflection coils.

3.3.1.1.1.5   V-Ramp—The V-ramp signal received from the image generator is also corrected and amplified in the CRT electronics to yield the required V-sweep input to the CRT deflection coils.

3.3.1.1.2   CRT Electronics/CRT Coils

3.3.1.1.2.1   Video (Corrected)—The video output signal drives the CRT to provide the desired luminance levels, contrast and gray shades. This signal has been corrected in the CRT electronics for gamma, raster geometry shading, and Farrand window shading. Other correction controls are available to compensate for luminance variations across an individual tube and to facilitate luminance matching at tube-to-tube interfaces.

3.3.1.1.2.2 H-Sweep (Corrected)—The H-sweep signal output from the CRT electronics drives the CRT H-deflection coils to produce the desired raster shape. The H-sweep signal has been corrected for pincushion and for center of deflection versus center of faceplate curvature effects which are geometric in nature. Other correction controls are included to compensate for extraneous image distortions and for errors in deflection yoke orthogonality.

3.3.1.1.2.3 V-Sweep (Corrected)—The V-sweep signal output from the CRT electronics drives the CRT V-deflection coils. Corrections similar to those noted above in Paragraph 3.3.1.1.2.2 are performed on this signal in the CRT electronics.

3.3.1.1.2.4 Focus (Static)—The static focus signal drives an independent focus coil (separate from the dynamic coil) on the CRT. This input sets the nominal spot size on the CRT face.

3.3.1.1.2.5 Focus (Dynamic)—The dynamic focus signal introduces focus corrections to compensate for spot size variations which are a function of beam deflection angle. These high frequency variations are introduced through a separate focus coil.

3.3.1.1.2.6 Focus (Video Drive)—The video drive focus signal introduces a focus correction to account for a displacement of the electron optical object (crossover) in the CRT with video drive

3.3.1.1.2.7 Astigmatism (Static)—The static astigmatism signals correct the beam for incidental departures in spot shape from a desired circular beam cross-section. Two orthogonal coil sets are used to control static spot shape.

3.3.1.1.2.8 Astigmatism (Dynamic)—The dynamic astigmatism signal corrects the beam spot shape for variations which are a function of deflection angle. These corrections are applied to a coil separate from the static astigmatism coil.

3.3.1.1.2.9 Raster Centering—The X and Y raster positioning signals are used to center the raster on the optical axis of the display channel.

3.3.1.1.2.10 Beam Centering—The beam is aligned to the CRT electron optic axis before applying astigmatism, focus, and deflection functions. Beam centering signals energize two axially displaced coils following the beam alignment coils. Centering signals correct for errors in beam direction introduced while optimizing the beam alignment controls.

3.3.1.1.2.11 Beam Alignment—The beam alignment signals drive a two-axis deflection coil which optimizes cathode lens for maximum beam current.

3.3.1.1.2.12 Screen Voltage—The screen voltage provides the second accelerating potential. Its value controls the maximum CRT brightness level and influences the tube live. A protective circuit is included to remove the screen voltage if deflection is lost.

3.3.1.1.2.13 First Anode Voltage—The first anode voltage is the first accelerating potential. It is set at a nominal regulated level.

3 3.1.1.2.14 Grid Bias—The grid bias level is supplied by the CRT electronics. The blanking signal is introduced at the grid.

3.2.1.1.2.15 Heater Voltage—An isolated heater voltage is supplied for each CRT by the CRT electronics.

40
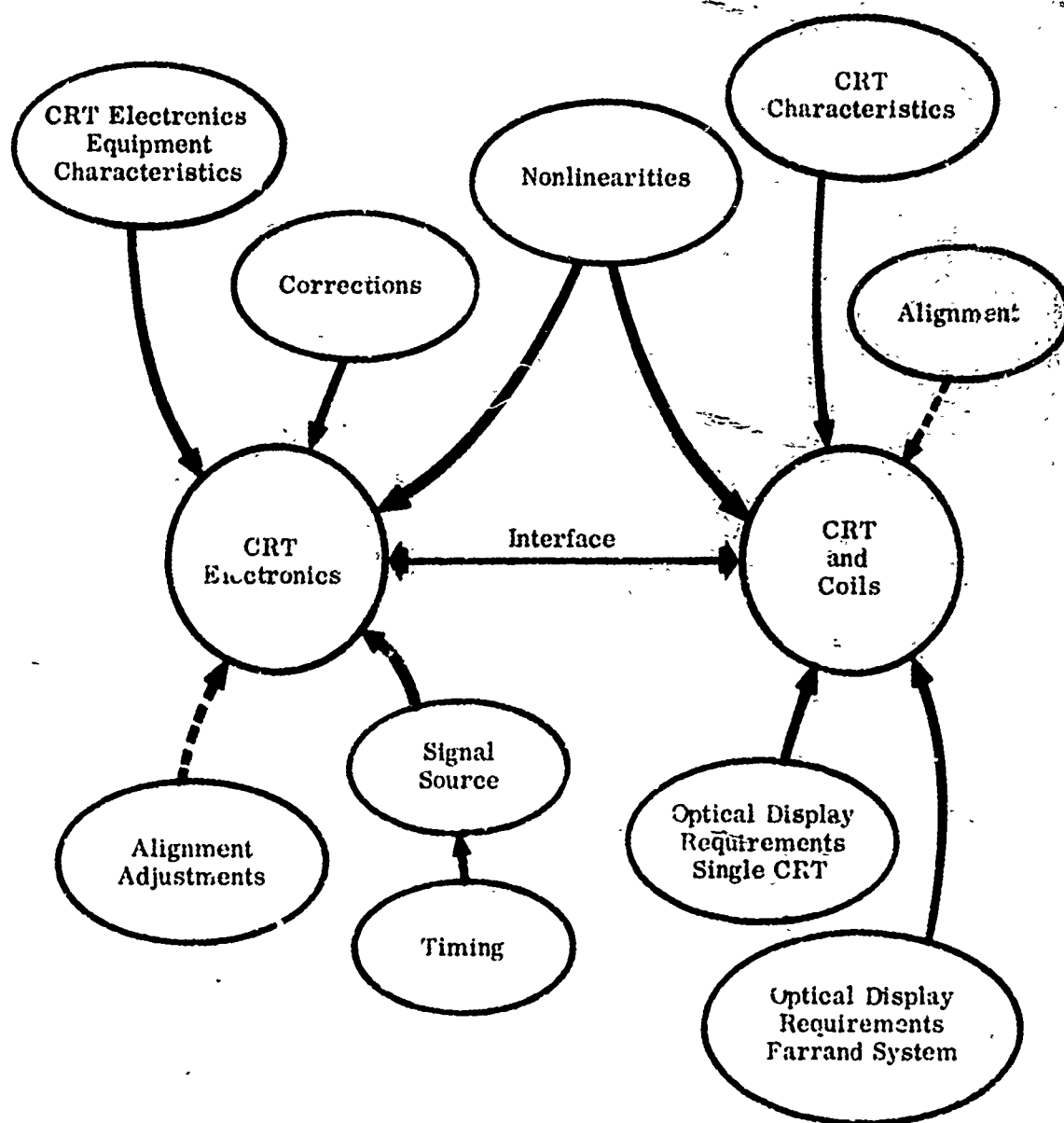
Figure 21. General Considerations Leading to the Interface Flow Chart
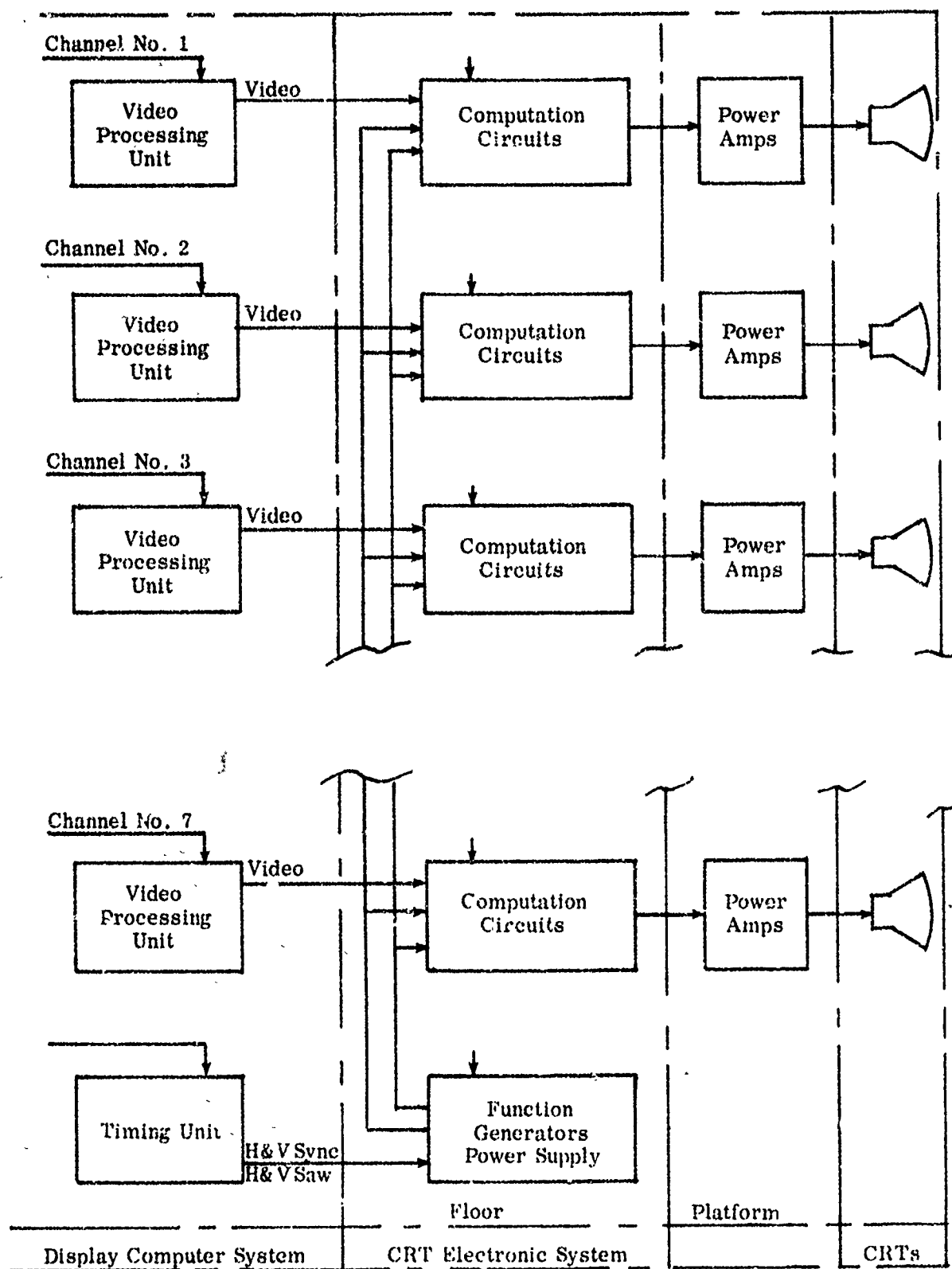
Figure 2′. CRT Electronics System Interfaces
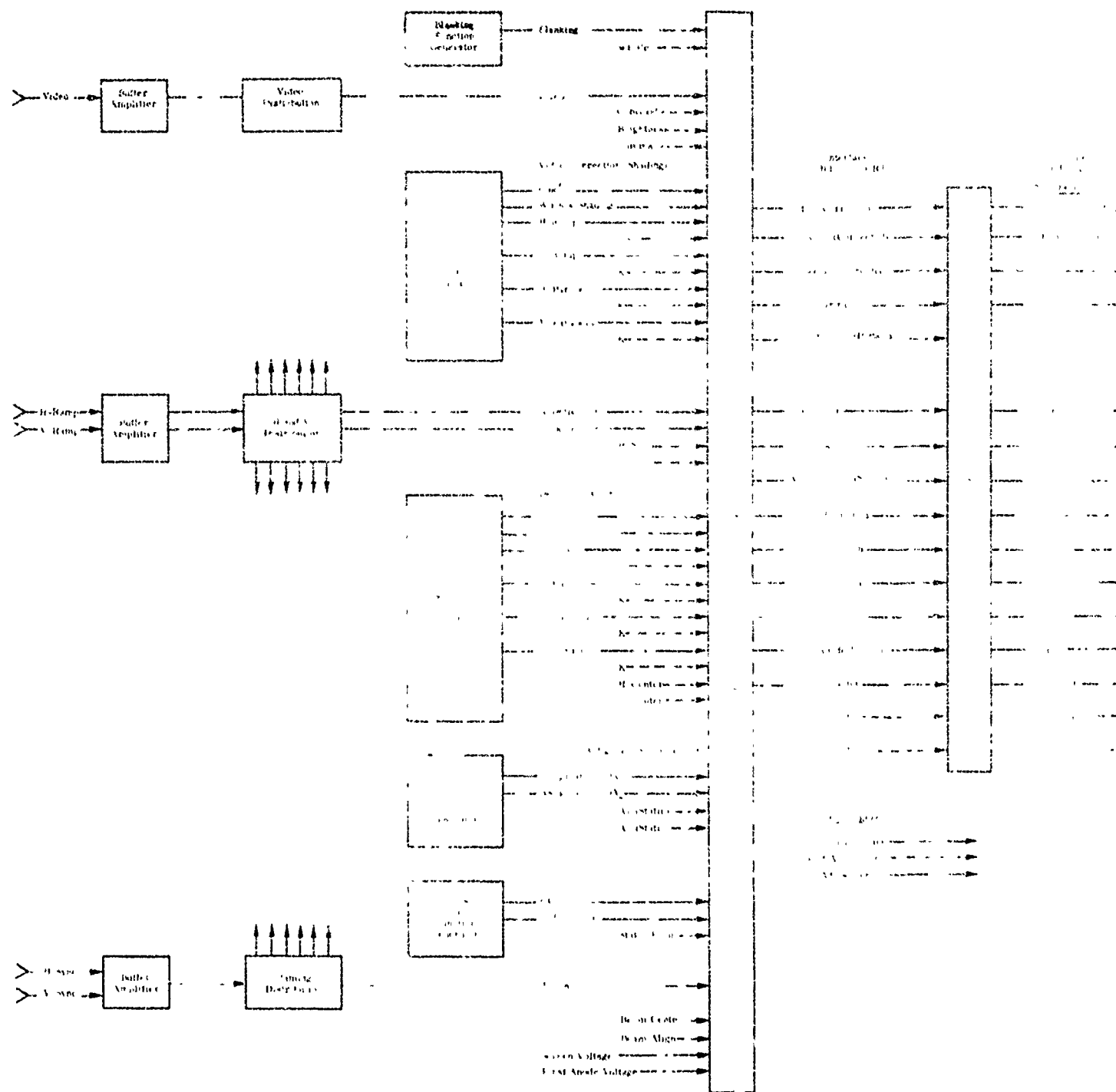
Figure 2
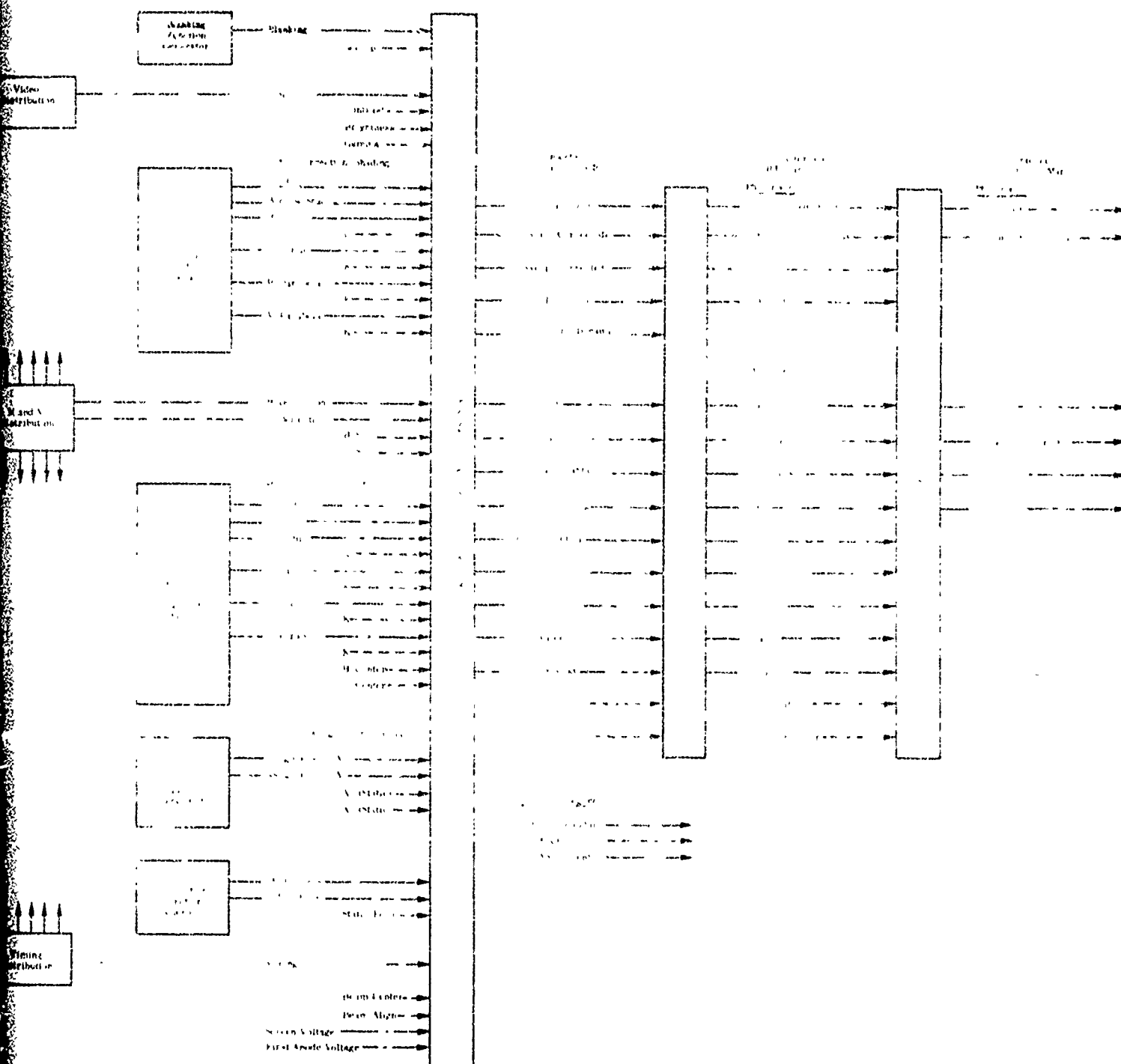
(Reve

Figure 23. Interface Flow Chart

3.3.1.2 Interface Flow Chart

The Interface Flow Chart, shown in Figure 23, identifies the functional interfaces that exist between the CRT electronics and its adjacent subsystems in the ASUPT visual simulation system. Functional inputs are shown entering at the left of the diagram. These inputs are received from the image generation subsystem. A common set of H and V ramp and H and V sync signals is received, processed, and distributed to the seven electronic circuit groups that serve individual CRTs. Each of the video inputs is different and thus is processed individually.

Next shown are the correction function generators with their identified outputs. This part of the diagram is intended to give a functional indication of the corrections required and does not necessarily show the final method of hardware implementation. Those correction adjustments which will be located in the cockpit area and used during alignment are shown as dashed line inputs. The large block in the center of the diagram includes all the analog function computers, mixers, power amplifiers, current, and voltage sources. The functional outputs of this block are the important interface signals which exist between the CRT electronics and the CRT. The upper group of signals contain high frequency components while the lower group are static current or voltage levels. Two mechanical alignment inputs to the CRT are shown at the bottom.

The transfer characteristics of the CRT and CRT coils determine the values of the next set of functional interfaces, CRT/Farrand optics. These interfaces contain the photometric and raster geometry functions which will be measured during the test and alignment of individual CRTs before assembly.

The last interface is between the Farrand optics and the viewer. Only those parameters which are modified by the optics are shown; however, the previous set of interfaces can be observed through the optics for test and alignment after final assembly. A sufficient selection of controls having adequate adjustment range will be located in the cockpit area.

3.3.1.3 Functional Interface Discussion

3.3.1.3.1 CRT Electronics/Image Generator Computer

3.3.1.3.1.1 **Video**—The analog video input signal from the image generator video processor is a non-composite standard waveform. This signal has a peak height of 1 volt and is terminated in 75 ohms. Each of the seven video signals is different and is processed separately in the CRT electronics. (If transmission line noise is determined to be a problem it would then be necessary to transmit the video signals over two coaxial cables in differential form to permit transmission line added noise to be removed via common mode rejection of the buffer amplifier.)

3.3.1.3.1.2 **H-Sync (Separate Sync)**—The H-sync standard pulse is rectangular in shape, -4 volts, and terminated in 75 ohms. The pulse width is nominally 2 microseconds wide with a rise time of 25 nanoseconds or less. The pulse rate for this 1023 line/frame system with 30 frames/second is 30.69 kHz. This input could also use a differential transmission line though it is not as critical as the video.)

3.3.1.3.1.3 **V-Sync (Separate Sync)**—The V-sync standard pulse is also -4 volts, rectangular, and terminated in 75 ohms. Its pulse rate is 60 Hz. The width of this pulse is nominally 20 microseconds and its rise time, 1 microsecond or less. This pulse signal will be properly timed to yield uniform and stable interlace. (A differential transmission line could be employed though it is not as critical as the video signal.)

3.3.1.3.1.4   H-Ramp—The H-ramp signal is triangular in shape, 1 volt high, and terminates in 75 ohms. This input determines the correct beam position in time; therefore, differential transmission should be used to the buffer amplifier. It is derived from the image computer's incremental line element count as shown in Figure 24(a) by integrating and smoothing as in Figure 24(b). A computed ramp is preferred to a locally generated ramp because it provides a more accurate indication of beam position which is required for correction of the H, V, and video signals. The H-ramp rise time is 26.5 microseconds, and its fall time is 5 microseconds.

3.3.1.3.1.5   V-Ramp—The V-ramp signal is also triangular, 1 volt peak-to-peak, and is terminated in 75 ohms. It should likewise be transmitted to the buffer amplifier with differential transmission. Its repetition rate is 60 Hz with an interlaced field time of 16.67 milliseconds of which 0.325 milliseconds is flyback time.

3.3.1.4   Function Interface Discussion—CRT Electronics/CRT (Coils)

3.3.1.4.1   Video (Corrected)

The corrected video signal drives the CRT cathode over a peak range of 150 (or 200) volts with sufficient power to overcome the stray and tube capacity. To determine the bandwidth and further specify the video parameters requires examining the television format. The H-line rate is given as

H-rate   =   (1023 lines/frame) (30 frames/second)   =   30.69 kHz

so the H-line time is 32.5 microseconds.

A 5-microsecond flyback (horizontal retrace) and minimum blanking of 1 microsecond allows an active line time of 26.5 microseconds.

The bandwidth requirements of a television system with 1,000 elements or spot diameters of deflection would require a nominal bandwidth of

$$\text{Video Bandwidth (BW)} = \frac{500 \text{ cycles}}{26.5 \times 10^{-6} \text{sec}} = 18.87 \text{ MHz}$$

Therefore, the exact element rate is double this figure or 37.73×10^{6} elements/sec.

A 20 MHz bandwidth will adequately reproduce the required display structure. A requirement of 40 MHz was considered in an attempt to improve the resolution of the digital pulses comprising the video waveform; however, this philosophy does not prove to give the best overall display. In general it is not necessary to resolve each bit or element in the display, but rather the information collectively conveyed. Thus a proper specification of the video amplifier requires flat response to within ±1 db out to 20 MHz. In addition a pulse response in the time domain is specified. Caution must be given to avoid a peaked response with overshoot on the pulse response since this will cause disturbing effects on the display. A rise time (10 to 90 percent) in about one bit time (25 nanoseconds, or slightly shorter is adequate. This conclusion is generally supported by past display system experience and specifically by the results of the Edge Smoothing study.

As shown in the Interface Flow Chart, Figure 23, the video signal is corrected for luminance variations introduced by the Farrand window transmission function and for the $(\cos^3 \phi)$ shading function produced by the mapping function required by the ASUPT raster. Other correction controls are available (H and V ramp, or saw, and parabola)

46

(a) Line Element Count (Or Line Count)

(b) Smoothed Ramp

(c) Smoothed Sawtooth

(d) Parabolic Function
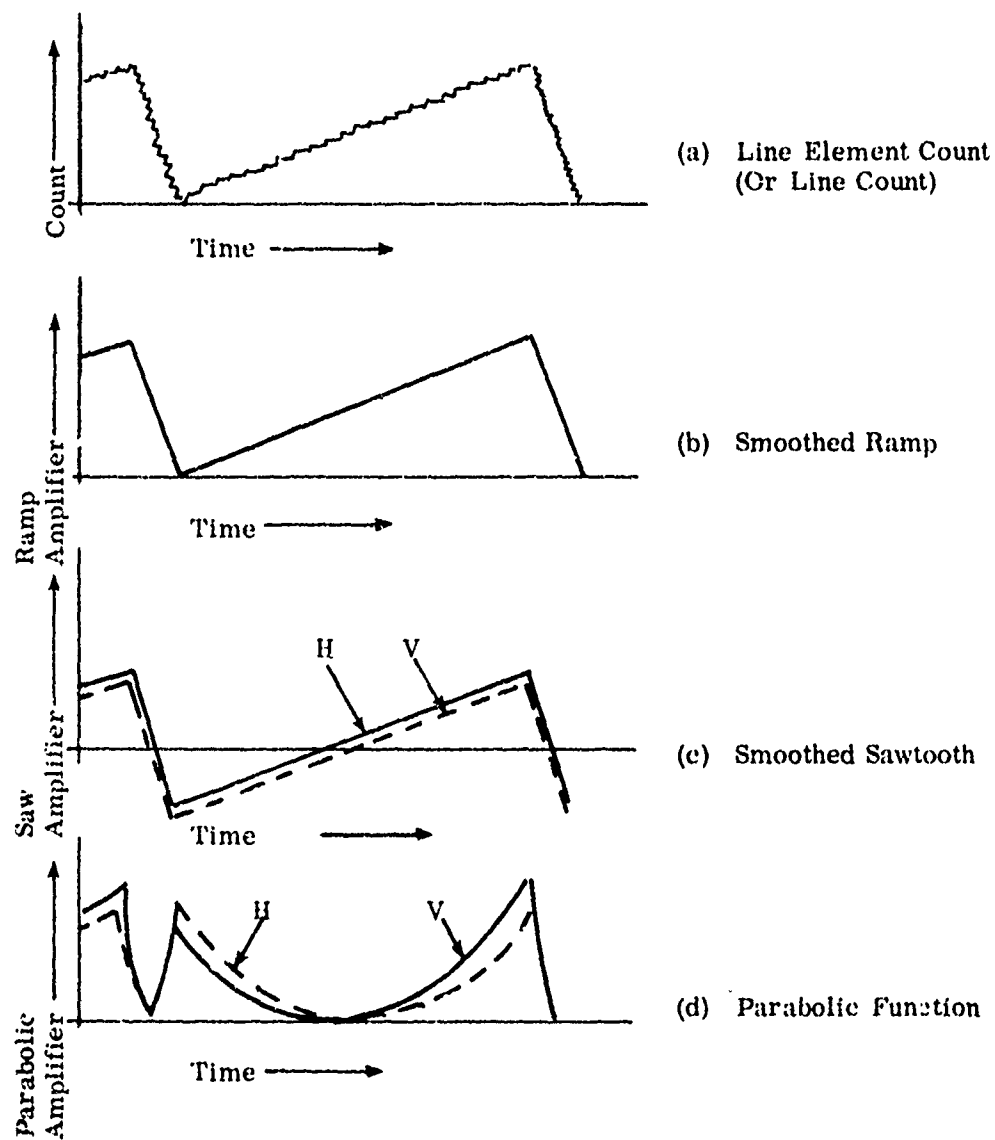
Figure 24. H and V Ramps, Sawtooth, and Parabolic Functions

47

to compensate for inherent luminance variations across individual tubes and to facili-
tate luminance matching at tube-to-tube image interfaces. The corrected video signal
is finally gamma corrected and applied to the CRT cathode. The video gain, or con-
trast, is set to optimize the gray shade levels. The brightness (luminance) control is
set to produce the desired peak luminance level.

It is recommended that video be applied to the ASUPT CRT cathode and the brightness
control and blanking be applied to the grid. There are many reasons for this. First
cathode drive for video gives a higher CRT transconductance, g_m, hence better drive
sensitivity. Second, the gamma (γ) characteristics of cathode drive are not as high
as with grid drive. Third, and very important, the input capacity of the cathode is
generally lower than the grid, thus wide bandwidth is not so difficult to achieve.

3.3.1.4.1.1 Video Corrections (Figure 23)

3.3.1.4.1.1.1 $\cos^3 \phi$

The $\cos^3 \phi$ video correction refers to that negative correction necessary to compen-
sate for the increased luminance level which would occur in a barrel distorted raster
as a function of field angle (Paragraph 3.2.4.1). This correction means decreased
current is required with increasing field angle.

The $\cos \phi$ shading function can be computed with IC analog circuit modules by form-
ing first the $\cos \phi$ by noting

$$\cos \phi = \frac{X^2 + Y^2 + R^2}{R}$$

where

    X = the position of the current point from the center of the computed display
        plane in the X direction (horizontal).

    Y = as above but in the vertical direction.

    R = 24-inch radius to eye point on CRT.

Analog voltages representing X and Y may be obtained from the H and V sawtooth volt-
ages derived from the original H and V ramp signals. This is shown in Figure 24(c)
with the time scale of the H and V waveforms altered to make the periods coincide.
As noted the V sawtooth is offset to account for the raster center displaced from the
CRT center.

3.3.1.4.1.1.2 Window Shading

A correction must be made for the increased attenuation of the Farrand window with
field angle. This correction is positive as compared to the $\cos^3 \phi$ raster shading
function which means increased beam current is required with increasing field angle.
The actual function must be specified by detailed measurements of the window which
will be used in the ASUPT system. To establish the general character of this correc-
tion, the data given in Figure 3 is used.

48

The function below fits the approximate Farrand window transmission functions closely, Figure 25.

$$T(W) = 1.00 - K_1 \phi^4$$

where

$$K_1 = 8.18 \times 10^{-6}$$

$$\phi = \text{field angle in degrees}$$

This window shading function can be generated by forming the field angle, ϕ, from X, Y and R using IC analog circuit modules. Thus the combined correction for CRT raster shading and Farrand window shading is

$$\frac{Cos^3 \phi}{T(W)} = \frac{Cos^3 \phi}{1 - K \phi^4}$$

The combined shading function is shown in Figure 26. Also shown is the $cos^3 \phi$ function. Initially the effect of $T(W)$ is almost negligible, but at the larger field angles it predominates. In fact, the combined function hits a low at about $\phi = 40$ degrees where it reverses. If the window were to be used at field angles greater than 45 degrees, it would be difficult to adequately correct for it. Thus in this combined shading function, the beam current and hence the screen brightness is decreased as a function of field angle from the on-axis values. However, at some field angle ($\phi = 40$ degrees), the beam current must then begin to increase as shown by Figure 26.

3.3.1.4.1.1.3   Extraneous Shading

Other extraneous shading influences which cause brightness variations over an individual CRT face will be compensated by the introduction of H and V saw and/or parabolic signals into the video correction circuitry as shown in Figure 24. These inputs will also facilitate the matching of luminance levels at the pentagonal segment boundaries.

3.3.1.4.1.1.4   Gamma

After all linear corrections are applied, the gamma correction is applied to force the CRT screen brightness to vary as a linear function of the corrected video. Gamma is determined by plotting the log screen brightness versus the log grid drive voltage as in Figure 8. The slope of the curve in Figure 8 yields a gamma of $\gamma = 2.6$. Thomas Electronics cautioned that an average gamma of $\gamma = 4.0$ should be planned. Rather than attempt to vary gamma with video drive as is experimentally found, it is recommended that the specific gamma characteristics of the ASUPT CRT be matched by gamma correction circuitry in the region of average to peak brightness.

3.3.1.4.2   H-Sweep (Corrected)

3.3.1.4.2.1   General—The horizontal sweep signal drives the H-deflection coil through a ±15 amp range (30 amps peak-to-peak) at a 30.96 kHz rate. This rate yields a 32.5 microsecond horizontal line time. Of this, 26.5 microseconds are active line time with a 5-microsecond flyback and a 6.0-microsecond horizontal blanking time. The H-deflection signal is corrected for pincushion, center of CRT face curvature versus center of beam deflection, and for extraneous departures in yoke orthogonality and/or image distortion.
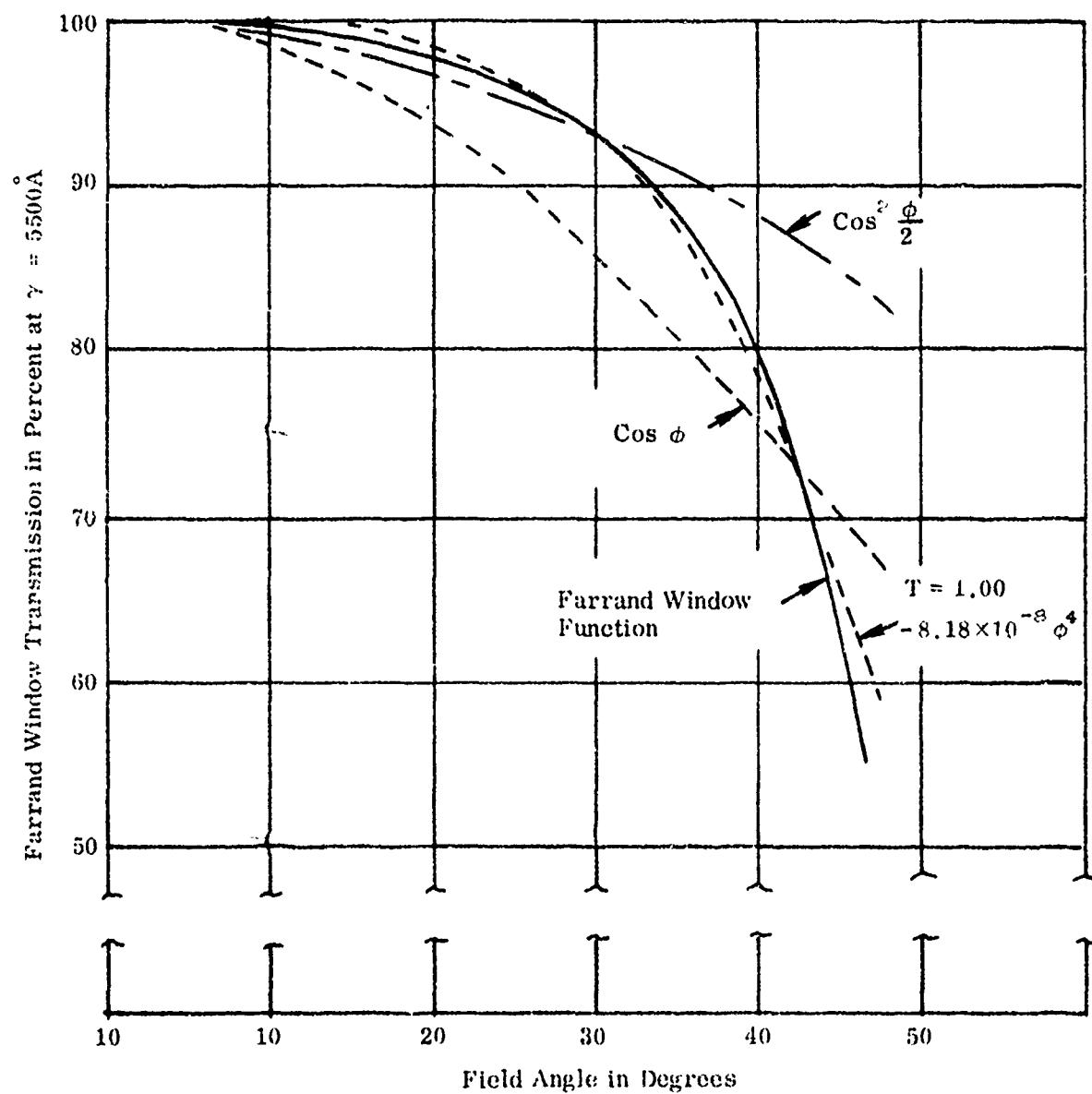
Figure 25. Farrand Window Shading Function
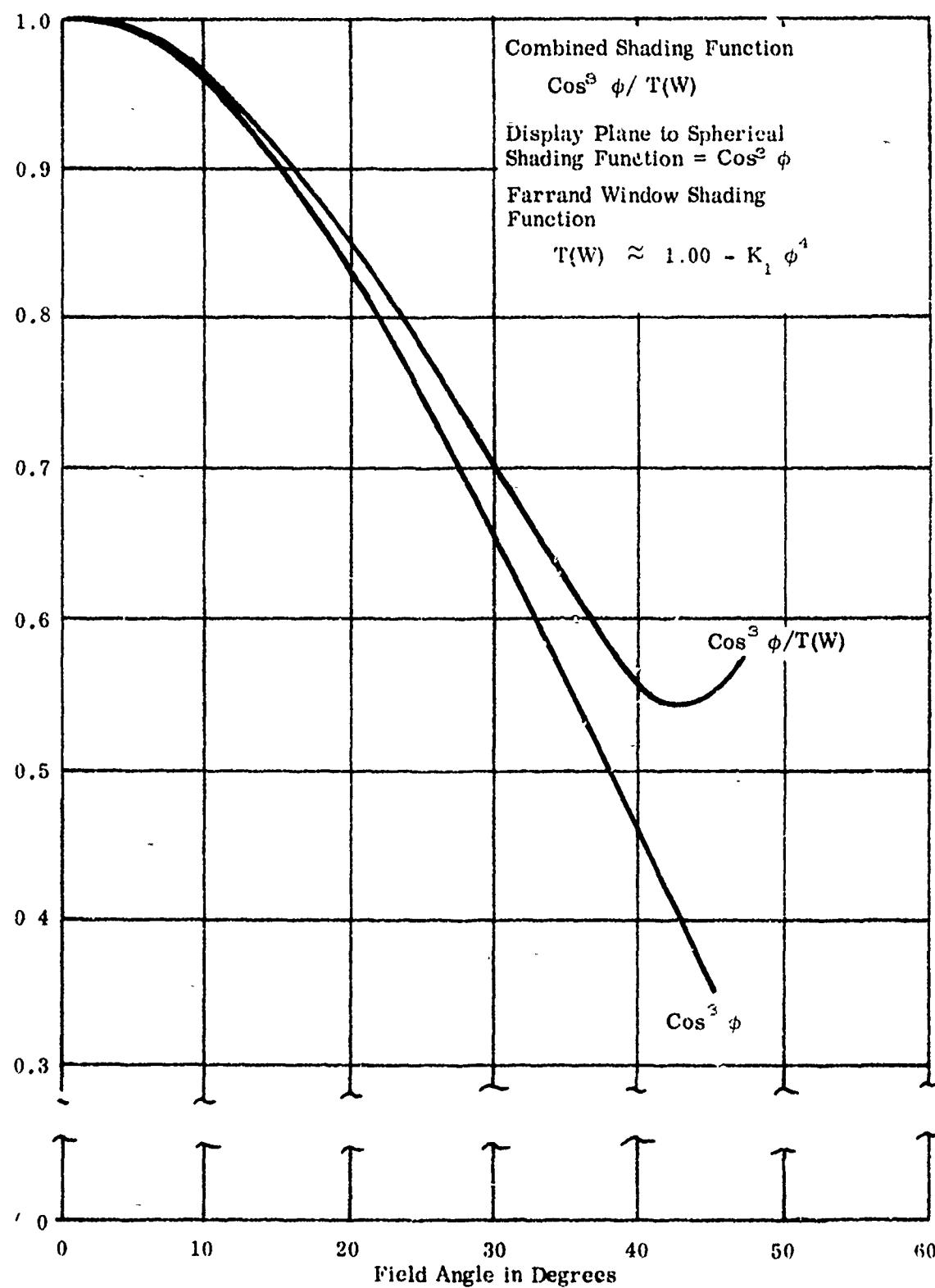
Figure 26. Combined Shading Function (Corrected)

3.3.1.4.2.2 Pincushion—It can be seen from the deflection geometry of Figure 27(b), that if the center of deflection were at the virtual eye point the proper raster will be written on the spherical CRT screen when the beam is deflected for a uniform raster on the computed display plane. This is true because the electron beam is in a drift space after passing through the deflection yoke and thus travels a straight path.

The required barrel distortion can be written on a spherical shaped CRT face by introducing the type of deflection correction normally used to eliminate the pincushion effect on flat faced CRTs. A separate deflection correction is recommended to compensate for the fact that the actual center of deflection is displaced from the center of curvature.

From electron beam deflection analysis the deflection field is

$$B = \frac{\text{Sin } \phi}{k}$$

Thus the value of B or its equivalent drive current I_D can be computed from a specified value of D. The horizontal component of B is from Figure 27(a)

$$B_x = \frac{X}{k\sqrt{R^2 + X^2 + Y^2}} \cong I_x$$

Thus the horizontal drive current corrected for pincushion is

$$I_x \cong \text{Sin } \phi_x$$

The cross-coupling of Y into I_x is evident in the expression

$$I_x \cong \frac{X}{k\sqrt{R^2 + X^2 + Y^2}}$$

The waveshape of this function is shown in Figure 28(a). Here it is illustrated that as the vertical position of the horizontal sweep increases the peak deflection current for the same length horizontal scan on the CRT screen can decrease.

3.3.1.4.2.3 Center of Curvature versus Center of Beam Deflection, CC/CD—The development of raster geometry and deflection correction functions in the previous paragraphs is considerably facilitated by assuming a CRT design where the center of curvature and center of beam deflection are located at the same point. This is not the case in the proposed CRT, so an additional correction is necessary. Figure 28(b) shows the (radial) deflection angle "ϕ" as a function of CRT face radius "R" and a deflection distance "D" in the computational plane. Deflection functions of the angle "ϕ" must be converted to equivalent functions of angle "θ". As before,

$$\text{Sin } \theta = k B$$

where

B   the deflection magnetic field.

θ the deflection angle.

$$\sqrt{X^2 + Y^2 + R^2}$$

$$D = \sqrt{X^2 + Y^2}$$

$$\text{Sin } \theta_X = \frac{X}{\sqrt{X^2 + Y^2 + R^2}}$$

$$\text{Sin } \theta_Y = \frac{Y}{\sqrt{X^2 + Y^2 + R^2}}$$
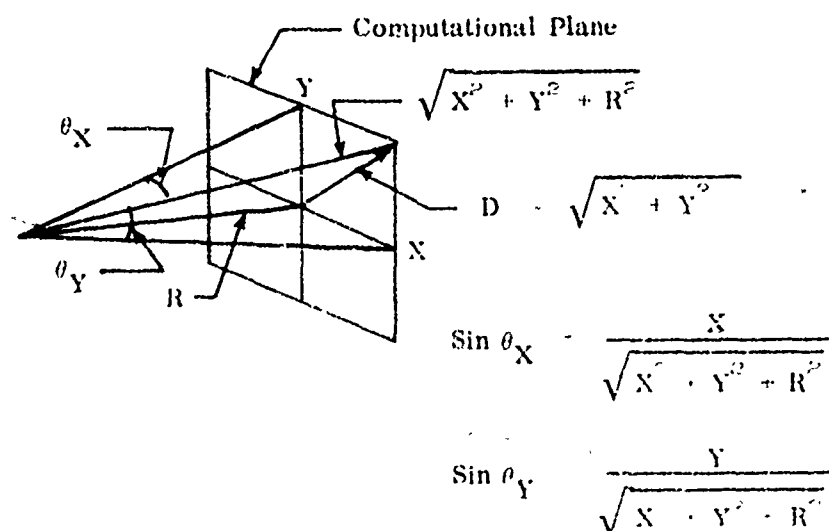
(a) Sine Function Analysis
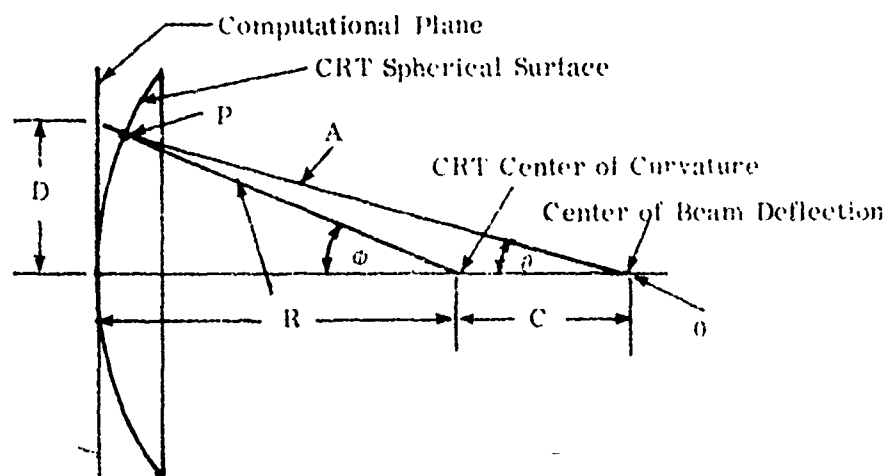
(b) Center of Curvature versus Center of Deflection

Figure 27. Deflection Geometry

$$I_x = \frac{X}{k\sqrt{X^2 + Y^2 + R^2}}$$

(a) "X" Deflection Current

$$\text{Sin } \phi_\gamma = \frac{D_\gamma'}{R}$$

$$\text{Sin } \theta_\gamma = \frac{D_\gamma'}{A}$$

Note: ϕ and θ are in two different planes

$$\frac{\text{Sin } \theta_\gamma}{\text{Sin } \phi_\gamma} = \frac{R}{A}$$
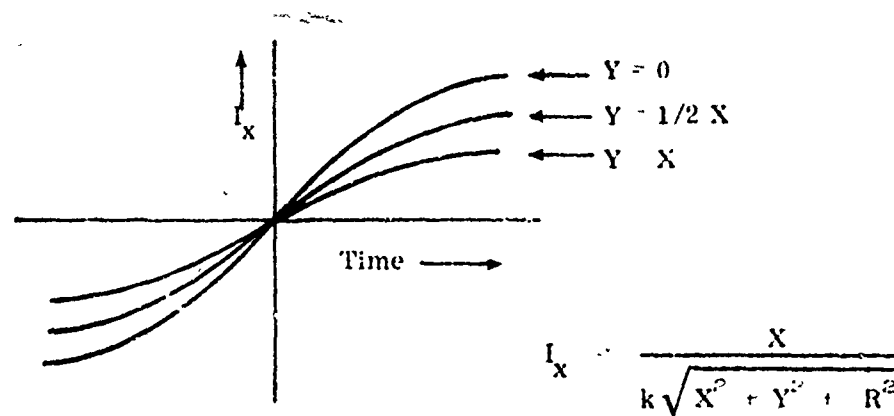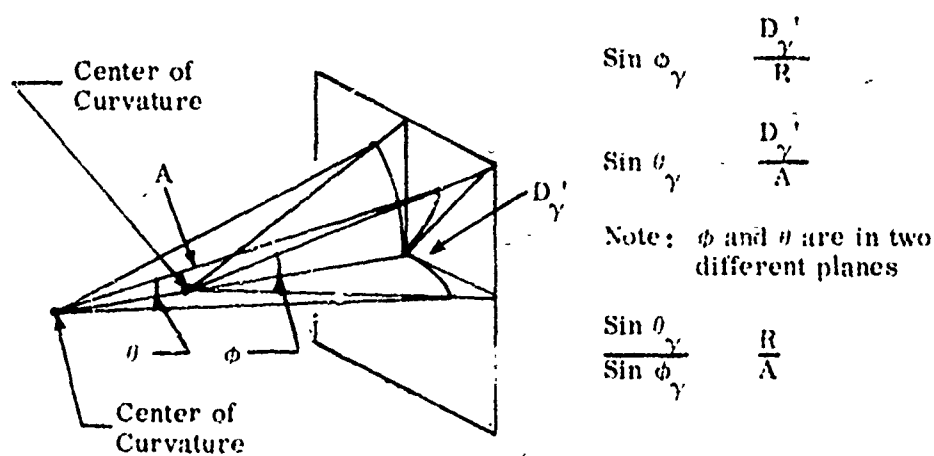
(b) C/C versus C/D Geometry

Figure 28. Corrections for a Deflection Center Displaced from the Center of Curvature

54

Thus for deflections originating at the center of curvature

$$\sin \theta = k \, B_1$$

and for deflections originating at the true center of beam deflection

$$\sin \theta = k \, B_2$$

Thus

$$B_2 = B_1 \frac{\sin \theta}{\sin \phi}$$

Applying the Law of Sines to the triangle A, R, C in Figure 28(b), the relation

$$B_2 = B_1 \frac{R}{A}$$

is obtained. Thus the CC/CD correction factor is R/A:

$$A = \sqrt{R^2 + C^2 + 2RC \cos \phi}$$

where

R and C = constants.

ϕ = the radial angle with its apex at the center of curvature.

From Figure 5 showing the proposed ASUPT CRT, the center of beam deflection is 32 inches, the center of curvature, R, is 24 inches, so C = 8 inches, and as noted earlier, ϕ ranges from zero on axis to 44.6 degrees at the pentagon point.

3.3.1.4.2.4   Extraneous Distortions—The two corrections discussed previously were functions of CRT and raster geometry. Other distortions can occur due to errors in electronic, optical, and mechanical components and also from misalignment errors.

Those image distortions which are symmetric about the axis can be minimized by introducing compensating amounts of H and V saw and/or H and V parabolic functions to the deflection signal. Figure 29 illustrates schematically the introduction of these functions at the front end of the H and V correction electronics. This approach permits examination of the H and V inputs to the major raster correction blocks and determination of the contribution of first yoke image distortion. Any window image distortion is the departure from a true linear sawtooth waveform.

The parabolic inputs correct the barrel and pincushion distortions, and the "saw" input corrects the orthogonality distortions. Figure 30(a) shows the linear horizontal sweep modulated by the V-parabolic signal to correct for barrel effects. In this case

$$H_{cor} = H_L \times K(V_{PAR})$$
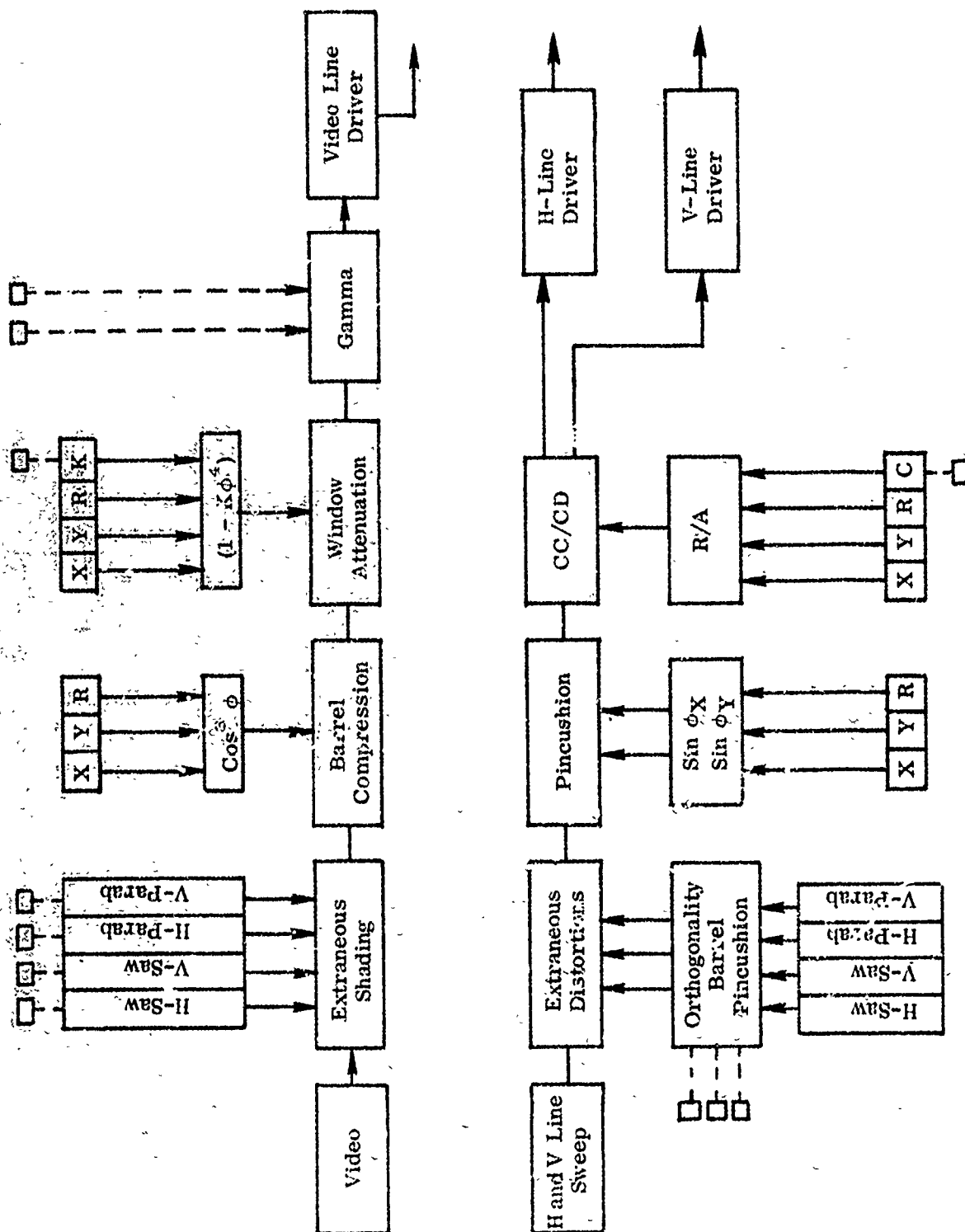
Figure 29. Video and Deflection Corrections

56

$$H_{cor} = H_L \left[K(V_{par}) \right] \text{ , where: } H_L = \text{Linear Sawtooth}$$

$$V_{par} = \text{Vertical Parabola}$$

Horizontal Sweep (H_L)   V-Parabola Correction
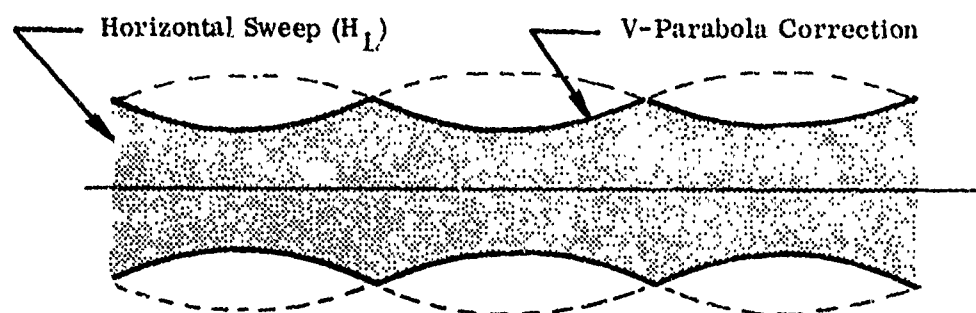
(a) H-Sweep Correction for Extraneous (Barrel or Pincushion) Distortion

$$H_{cor} = H_L + K(V_{saw})$$

Horizontal Sweep (H_L)
(Fine Structure)   V-Saw Correction
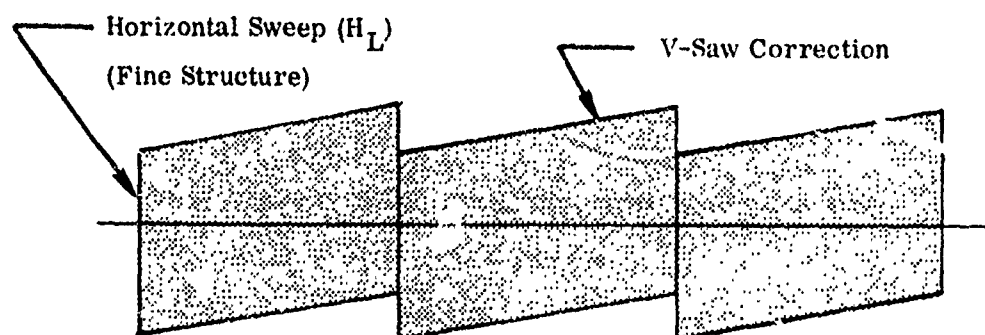
(b) H-Sweep Correction for Orthogonality Errors

Figure 30. Raster Distortion and Orthogonality Corrections

The sign (i.e., parabola opens up or down) shape of the modulation envelope determines whether pincushion or barrel corrections are introduced. Figure 30(b) shows the horizontal sweep corrected for orthogonality distortions. The corrected wave for this is expressed as

$$H_{cor} = H_L + K(V_{SAW})$$

Before making this correction the deflection yoke is rotated to align the H-scan to the exact horizontal axis. Thus electronic orthogonality corrections will not be required in the vertical direction. The wave shape of these "saw" and parabolic corrections are shown in Figure 24. Only one polarity is shown.

3.3.1.4.3 V-Sweep Corrected

3.3.1.4.3.1 General—The vertical sweep signal drives the V-deflection coil through a 30-amp peak-to-peak excursion. The upper and lower limits of the vertical drive current are not equal as shown in Figure 24 since the peak of the pentagonal raster is a greater distance from the CRT center than the base. The vertical sweep rate is 60 Hz. The V-field time is 16.67 milliseconds and the flyback time is 325 microseconds.

The V-deflection signals are corrected for pincushion, center of curvature versus center of deflection, and for extraneous distortions, as shown on the block diagram of Figure 29.

3.3.1.4.3.2 Pincushion—The V-pincushion correction follows the same development as that in Paragraph 3.3.1.4.2.2 (H-pincushion) except that the final expression for corrected deflection current is

$$I_V = \frac{Y}{k\sqrt{R^2 + X^2 + Y^2}}$$

Its wave shape is similar to that shown in Figure 28(a).

3.3.1.4.3.3 Center of Curvature versus Center of Beam Deflection—The V correction factor for CC/CD is the same as that derived for H in Paragraph 3.3.1.4.2.3. The same function generator for R/A is used by both correction circuits.

3.3.1.4.3.4 Extraneous Distortion Corrections—Extraneous pincushion or barrel distortion in the vertical direction of the raster can be minimized by mixing quantities of H and V parabola signals with the H sweep signal. The wave shapes for both H and V image distortion are shown in Figure 31. The distorted raster (one dimensional), the form of predistortion required, and then the corrected sweep waveform are illustrated.

The analytical form of the correction waveform is indicated. No orthogonality correction is required for the deflection signal since one axis of the raster is aligned exactly and then the other raster axis is corrected for exact orthogonality.

3.3.1.4.4 Focus (Static)

The static focus signal drives the static focus coil of the CRT with a nominal current of 500 milliamps. This current should be regulated to better than 0.1 percent
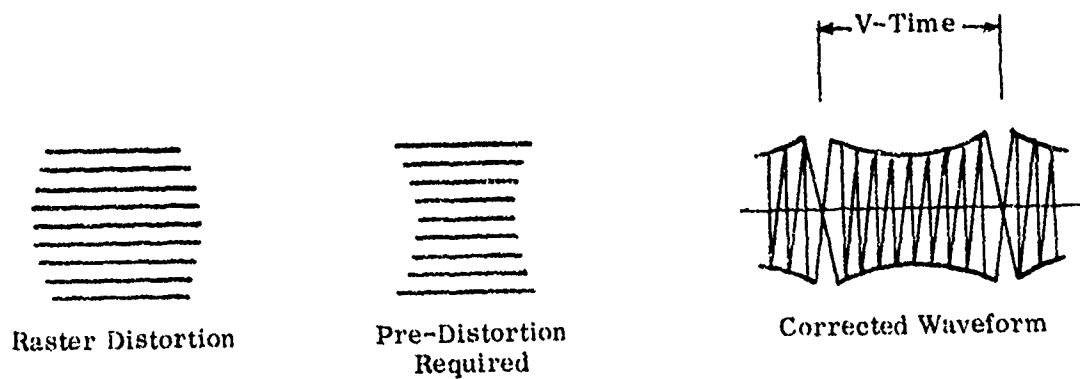
(a) H-Corrections

$$H_{(Corrected)} = K_1 H \left(K_2 V + K_3 V^2 \right)$$
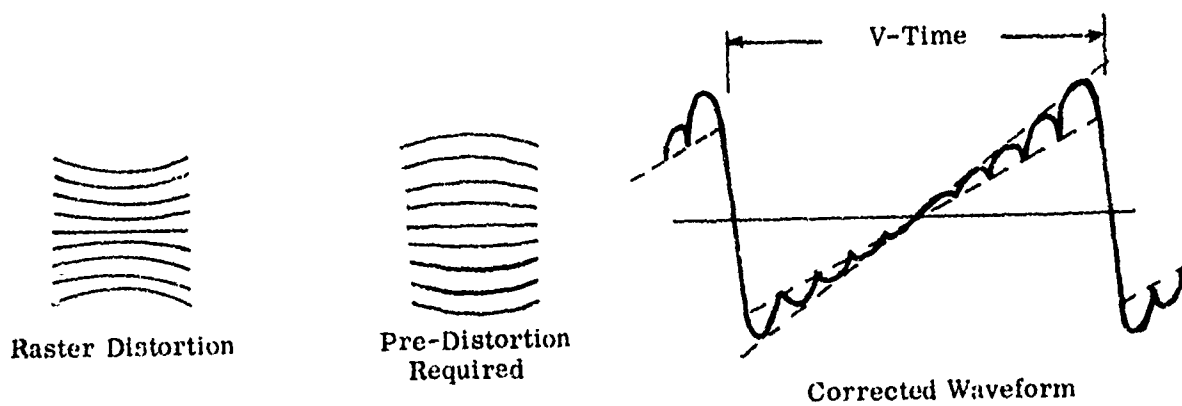
(b) V-Corrections

$$V_{(Corrected)} = K_1 V + H^2 \left(K_2 V + K_3 V^2 \right)$$

Figure 31. Raster Image Distortion Corrections

59

3.3.1.4.5 Focus (Dynamic)

A dynamic focus signal drives a separate focus coil through an assumed nominal range of 0 to 500 milliamps. This signal varies as a function of beam deflection angle and thus contains H and V sweep frequency components. Therefore, the coil must be capable of operating at a maximum frequency of approximately ten times the H-rate or 307 kHz to adequately reproduce the transitions at the H line edge.

By means of an analysis, the amount of dynamic focus correction was calculated to be 2.5 percent. This is considered negligible so it is recommended that this correction not be included in the initial specification.

3.3.1.4.6 Focus (Video)

A third focus correction is applied to compensate for the defocusing effect of large video input voltage variations. These high frequency video components are applied to a third focus coil which maintains focus as a function of the video waveform smoothed over several resolution elements, if necessary.

3.3.1.4.7 Astigmatism (Static)

The static astigmatism signals vary over an estimated range of 0 to 500 milliamps. These signals drive an 8-coil astigmator assembly.

3.3.1.4.8 Astigmatism (Dynamic)

Dynamic astigmatism corrections are applied at the sweep rates (30.69 kHz fundamental) to a separate 8-pole or quadrapole assembly.

By means of an analysis, the amount of dynamic astigmatism correction was calculated to be 1.5 percent. This is considered negligible so it is recommended that this 1.5 percent correction not be included in the initial specification; however, it may be necessary to correct for the dynamic astigmatism requirement of the ASUPT raster as shown in Figure 15.

3.3.1.4.9 Raster Centering

The H and V raster centering signals drive a separate set of deflection coils. The signal range of ±500 milliamps will allow ±5 percent (full raster) movement. A separate offset V center of about 10 percent full sweep is required to place 1000 scans between pentagon point and base.

3.3.1.4.10 Beam Centering

Each of the two axially displaced beam centering coils receives a nominal 500 milliamps from a regulated power supply.

3.3.1.4.11 Beam Alignment

The two beam alignment coils each receive an estimated 500 milliamp regulated drive current.

3.3.1.4.12 Screen Voltage

The screen voltage is set at 38 kilovolts. The maximum screen current is 6 milliamps.

66

3.3.1.4.13　First Anode Voltage

The first anode voltage is approximately 1000 volts dc. The estimated supply current capability is 1 to 2 milliamps, though the g_2 electrode is non-intercepting and should draw negligible current.

3.3.1.4.14　Grid Bias (G-2)

The grid bias is set at a nominal 180 volts. The estimated drain is likewise negligible, but the grid drive should be capable of at least 1 milliamp current drive.

3.3.1.4.15　Heater Voltage

The heater voltage is 6.3 volts at 600 milliamps, preferably dc to avoid hum or noise injection.

3.3.1.5　Functional Interface Parameters

The following is a listing of the parameters for the functional interfaces between the CRT electronics and the CRT and coil assembly.

     a.　Voltage level (or range).
     b.　Current level (or range).
     c.　Regulation.
     d.　Ripple or noise.
     e.　Stability.
     f.　Bandwidth.
     g.　Sweep rate.
     h.　Timing.
     i.　Wave shape.
     j.　Corrections.
     k.　Adjustment controls.

Each interface can be described by specifying the value of one or more of these parameters. Table II shows which parameters are applicable to a particular interface.

A brief description of each follows:

     a.　Voltage Level or Range—A fixed potential with adjustment range, or the limits of a variable voltage.

     b.　Current Level or Range—A specific current and its adjustment range, or the limits of a variable current.

     c.　Regulation—The allowable variation in level as a result of ±10 percent input power variation and load variations.

     d.　Ripple or Noise—The maximum peak-to-peak power line ripple or noise pickup.

     e.　Stability—The maximum level change per 8 hours over a long time span.

     f.　Bandwidth—The band of frequencies included in the signal.

     g.　Sweep Rate—The line rate (for horizontal deflection) or the field rate (for vertical deflection).

Table II

MATRIX CHART—FUNCTIONAL INTERFACES VERSUS ELECTRONIC
SIGNAL PARAMETERS

CRT/CRT Electronics Interfaces	Quantity/CRT	Electronic Signal Parameters										
		Voltage Level or Range	Current Level or Range	Regulation	Ripple or Noise	Stability	Bandwidth	Sweep Rate	Timing	Wave Shape	Corrections	Adjustment Controls
Video (Corrected)	1	X					X				X	X
H-Sweep (Corrected)	1		X					X	X	X	X	X
V-Sweep (Corrected)	1		X					X	X	X	X	X
Focus (Dynamic)	1		X				X					X
Focus (Video)	1		X				X			X		
Astigmatism (Dynamic)	2		X				X					
Bias (G-1)	1	X		X	X	X	X		X	X		X
Focus (Static)	1		X	X	X	X						X
Astigmatism (Static)	2		X	X	X	X						X
Raster Centering	2		X	X	X	X						X
Beam Centering	4		X	X	X	X						X
Beam Alignment	2		X	X	X	X						X
Screen Voltage	1	X		X	X	X						X
First Anode Voltage	1	X		X	X	X						X
Heater Voltage	1	X										

62

h. Timing—The field time, line time, flyback time, etc.

i. Wave Shape—The general shape such as ramp, saw or parabolic.

j. Corrections—The signals that have been added to correct for raster geometry, extraneous distortion or cross-coupling.

k. Adjustment Controls—What parameter is measured during adjustment, control location, cockpit or floor electronics.

3.3.1.6 Specify Required Value, Wave Shape, Etc., of Each Electronic Signal Parameter

Paragraph 3.3.1.5 listed the pertinent electronic signal parameters and gave a brief description of each term. A matrix chart was given showing interfaces versus electronic signal parameters with check marks noting the applicable blocks. Fifteen tables were compiled to show an individual electronic signal parameter specification sheet for each interface. (These tables can be found in the "Cathode Ray Tube Electronics Definition Study" issued as a separate report under this contract.)

It was not possible to accurately determine at this time all the electronic signal parameters. Some parameters were best estimates based on past experience in order to generate a CRT electronic system specification. Final specification of these electronic signal parameters require experimental work with a full-size ASUPT CRT due to the empirical nature of the complex electron optical situation.

3.3.1.7 Establish Feasibility of Generating Required Parameters for Each Functional Interface

There are presently identified some 15 major CRT electronics system interfaces. In Figure 19 the CRT electronic system was established in general form. The above discussion defined and discussed, in detail, these major system interfaces. The tables referenced in Paragraph 3.3.1.6 specified, in the best form presently possible, the value, range, stability, adjustments, and other pertinent electronic signal parameters for each system interface.

The question of feasibility is complicated in this instance by the relative complexity of the system and the preliminary nature of some of the data inputs at this point; however, with a practical view in mind, each of the system interface specifications in paragraph 3.3.1.6 was examined from the standpoint of past experience to see the developments exceeded state-of-the-art performance specifications. When this is done, there are only two system interfaces which represent beyond present demonstrable state-of-the-art performance capabilities. These two are the video (corrected) and the H-sweep (corrected).

In both the video (corrected) and the H-sweep (corrected) it is the power output stage which poses the primary question of feasibility. In Paragraph 3.3.2, the physical interfaces of the CRT electronics system are studied in order to define the system better.

3.3.2 HARDWARE DEFINITION

3.3.2.1 Define Physical Configuration

A physical configuration for the overall system is shown in Figure 1 for the ASUPT visual system. Note that the CRT electronics system is shown divided with a portion

on the motion platform and a portion mounted nearby. Due to the large load on the motion table, the CRT electronics system is distributed to minimize the load.

Though Figure 1 is schematic in nature, this CRT electronics system block diagram clearly indicates a natural division for physical location of the particular circuit blocks involved. It has been determined that all low level circuitry be located off the motion platform and all high level circuitry driving the CRT interfaces directly be located on the motion platform near the associated CRT. The logic of this is that as shown by the interface flow chart, Figure 23, there is a large amount of common circuitry such as low level power supplies and common correction functions, which can be located remote from the actual CRT. Additionally, there are a number of circuit operations including the blanking generation, H and V corrections, video shading corrections, gamma and similar operations which can be performed at low levels and sent to the CRT driver circuits via a low noise transmission method such as a differential coaxial cable arrangement.

Figure 19 gives the complement of circuit blocks to be located on the motion platform by noting those blocks directly connected to the CRT/CRT coils. This yields the output stages of each of the 15 system interfaces identified in Paragraph 3.3.1.4. There will, of course, be some minor additions not covered by this formatting procedure such as the sweep protection circuit (i.e., high voltage relay and driver). It is recommended that each CRT with its associated CRT electronics/platform mount be contained within a moderately compact structure or enclosure which provides an EMI shield. All inputs to this CRT enclosure should be via the 75 ohm differential coaxial cable transmission method to avoid pickup or CRT system interaction. To insure a complete electrostatic shield, even the CRT faceplate must be included. A convenient method should be employed to provide a contiguous shield from the CRT enclosure to the CRT faceplate. This electrostatic shield is particularly important since the 5-6 milliamp electron beam when modulated at wide bandwidth constitutes a moderately strong signal source which can radiate to lower level high gain amplifiers and result in circuit oscillation and cross-coupling of adjacent CRT channels.

In addition to electrostatic shielding the CRT enclosure should provide effective magnetic shielding. The high velocity beam at 30 kilovolts will tend to minimize the problems of stray magnetic fields, but it is wise to plan on magnetic CRT shielding.

All focus deflect components should be mounted in mechanical mounts with provisions for positioning in Z (axial), X and Y (centering), and pitch and yaw (angular alignment). Setting accuracy on the deflection yoke is most critical and this mount should be capable of smoothly positioning to a mil. The CRT and all focus deflect components should be mounted in such a way as to accurately reference the angular orientation. It is anticipated that all work on the individual CRT system will be done within the CRT enclosure. Due to the complexity and weight the completely aligned CRT system is transferred to the motion platform and referenced to exact location both for focus and angular alignment from the CRT enclosure.

With regard to circuit block placement, it will be necessary to place both the video amplifier and the sweep circuits in the immediate vicinity of their respective loads. The video amplifier performance is critically dependent on electrical capacity; thus the output tubes and load must be placed close to the CRT cathode terminal. It is preferable to keep the wiring and stray capacity to a minimum, thus the leads must be short.

The sweep drivers both H and V should also be located near their loads. Of course the H-driver is the more critical. It should be so configured that its lead to the H-coil is very short and designed to minimize both resistance and inductance in view of the

54

exceedingly high rate of current change with time. The vertical driver is less critical, but due to the required cross-coupling from the corrections, the V-driver contains H-sweep waveform components.

3.3.2.2 CRT Electronic Equipment Breakdown

The CRT electronic equipment is subdivided into the following groups:

    a.   Input buffer and processing circuits.
    b.   Function generators.
    c.   Distribution amplifiers.
    d.   Mixing circuits and local adjustment controls.
    e.   Line drivers.
    f.   Power supplies (local).
    g.   Power amplifiers.
    h.   Adjustment controls (remote).
    i.   Power supplies (remote).

The first six subgroups are located in floor-mounted electronic cabinets. The last three are located on the motion platform.

The hardware subgroups are described as follows:

    a.   Input Buffer and Processing Circuits—These circuits receive the input
         signals from the image computer and convert them to levels and shapes
         which are compatible with the following electronic analog mixers, gen-
         erators, or analog function computers. The input buffer receives the
         video, sync, and ramp inputs from image generator.

    b.   Function Generators—Various functions such as H and V saw, ramp,
         sin ϕ, cos ϕ, are generated once and distributed to the appropriate
         mixer or computer.

    c.   Distribution Amplifiers—To distribute signals generated by the function
         generators.

    d.   Mixing Circuits and Local Adjustment Controls—These circuits include
         the analog computer adders, multipliers, and weighting potentiometers.
         All other local adjustment controls are included.

    e.   Line Drivers—The dynamic signals computed or processed in the local
         electronics at low levels are sent to their respective power amplifiers
         on the platform via low impedance line driver circuits.

    f.   Power Supplies—The local power supplies provide power for all floor-
         mounted electronic equipment and for the platform-mounted power
         amplifiers.

    g.   Power Amplifiers—The low level dynamic signals such as video, sweep,
         etc., are amplified to the required voltage or current levels by power
         amplifiers located on the platform.

    h.   Adjustment Controls (Remote)—Those adjustments that require monitor-
         ing of the CRT to determine adjustment results will be located in the
         control package.

i. Power Supplies (Remote)—Only the high voltage supplies, screen at 35 kilovolts and first anode at 1.0 kilovolt and possibly the H and V sweep and video amplifier power supplies are located on the platform.

3.3.2.3 Equipment Physical Parameters

The following is a listing of the CRT electronics physical parameters considered in the study. Most are self-explanatory. Where applicable, notes are added.

a. Quantity—Number required per CRT system.

b. Size—Nominal volume, may be redistributed.

c. Weight—Is platform overloaded? Are special carrying fixtures required?

d. Shape—Does shape complicate mounting or servicing?

e. Location—Floor versus platform.

f. Accessibility—Can adjustment be made easily?

g. Mounting Constraints.

h. Cabling—Will cables affect platform movement or load down cable drivers?

i. Life—Will short life cause excessive down time? Can short-lived components be replaced easily?

j. Maintainability.

k. Power Requirements—Power required to operate the circuits.

l. Power Sequence.

m. Cooling—Primarily the power load which must be dissipated.

n. Ambient Temperature.

o. EMI Radiation.

p. Mangetic Radiation.

q. X-Ray Radiation.

r. Noise Radiation.

3.3.2.4 Matrix Charts—Electronics Components versus Physical Parameters

Table III is an example of matric charts constructed for each of the CRT electronic interfaces. These charts illustrate the equipment physical parameters which are applicable to particular electronic components associated with the interface. Those components which are platform mounted were detailed in this study since space, weight, and mounting constraints are critical in this area. No particular problems are expected with the floor-mounted electronics. In general, most attention is given to the output drivers associated with each of the CRT interfaces.

66

Table III

MATRIX—CRT ELECTRONICS EQUIPMENT PHYSICAL PARAMETERS

Item No.	Equipment Parameter	Input Buffer and Processing Circuits	Function Generators	Distribution Amplifiers	Mixing Circuits and Local Adjustment Controls	Line Drivers	Power Supplies (Local)	Power Amplifiers	Adjustment Controls	Power Supplies	Cables
				Floor Mounted					Platform Mounted		
1.	Quantity										
2.	Size										
3.	Weight										
4.	Shape										
5.	Location										
6.	Accessibility										
7.	Mounting Constraints										
8.	Cabling										
9.	Life										
10.	Maintainability										
11.	Power Requirements										
12.	Power Sequence										
13.	Cooling										
14.	Ambient Temperature										
15.	EMI Radiation										
16.	Magnetic Radiation										
17.	X–Ray Radiation										
18.	Noise Radiation (Audio)										

3.3.2.5 Determine the Value or Expected Range of Equipment Physical Parameters

3.3.2.5.1 General

This section discusses the determination of the equipment physical parameters employing the matrix chart shown in Table III as a systematic vehicle of study. The major CRT electronics system interfaces will, as stated, show a one-to-one correspondence to electronic components of interest. To completely specify the entire system is beyond the scope of this study. Primarily, the major components which contribute to size, weight, and power requirements on the motion platform were specified. As noted, these specifications are based on a study of the ASUPT system and the knowledge of past experience to guide parameter selection, in terms of size and weight. Approximate upper bounds on the power requirements were calculated to establish an upper limit on the power required for the CRT electronics/platform mounted. This data was summarized in separate tables, one for each major system interface. (These tables can be found in the "Cathode Ray Tube Electronics Definition Study" issued as a separate report under this contract.) The platform mounted portion of these electronic components (interfaces) involve the power driver stage that interfaces with the CRT/CRT coils. All remaining circuitry will be floor mounted and will constitute a far less stringent problem in terms of size, weight, power and/or location.

To determine the power required of each electronic component, the circuit type associated with each interface was considered and upper power limit requirements were calculated. In addition, the power requirements and weights of a portion of the power supply circuitry discussed in Paragraphs 3.3.2.5.1 and 3.3.2.5.4 were determined. This portion of the power supply circuitry could be remoted from the individual CRTs with adequate shielding and filtering to assure minimum fluctuations due to pickup. The total weight and power at each CRT could then be reduced.

3.3.2.5.2 Video (Corrected)

The video amplifier, at least the power output stage, represents a difficult circuit block. It must drive the CRT cathode lens with an exceedingly large swing of 150 volts or more and with a wide bandwidth of approximately 20 MHz. For this reason, the video output stage will drive the CRT cathode, and bias will be placed on the grid.

Several other designs offer some background experience in this type of drive circuit. The General Electric computer display system, NASA II, employed an excellent video amplifier. A report by C. V. Girod, Jr., and L. L. Pourciau, AMRL-TR-67-61, titled "Study and Development of Television Projector Video Amplifier Techniques" discussed the problems of developing a wide-band (30 MHz) high-level (350 volts peak-to-peak) video amplifier.

It was decided that the ASUPT video amplifier be a vacuum tube design to provide immunity from arc damage to itself and yield arc isolation for the remaining ASUPT CRT electronics. A preliminary design was performed to give greater practical value to the physical parameter estimates.

Video driver power is 560 watts worst case. With consideration of the efficiency of a power supply (located at CRT), this total power could run as high as

$$P = 1 \text{ kilowatt/CRT.}$$

3.3.2.5.3 H-Sweep (Corrected)

The horizontal sweep driver represents the most difficult circuit in the entire ASUPT CRT electronic system. This sweep is, roughly speaking, 3-1/2 times higher power than in color television. Since it must also be faster, it is easily a magnitude more difficult a circuit problem.

Past experience in this area includes the switched sweeps on the NASA II computed display simulator. To hold the power dissipation within reasonable bounds, a circuit technique of switching the driver transistor power supplies was used. Power transfer techniques reduced the power dissipation in the output stage by more than three to one. This deflection amplifier meets the following performance specifications.

> Bandwidth—DC to 0.5 MHz, ± 3 db
>
> Yoke Current—30 amperes peak-to-peak
>
> Yoke Voltage—±110 volts
>
> Blanking Time—approximately 15 microseconds

The deflection system described above was specifically designed to provide a precise rotatable raster scan for a 70-degree color CRT.

During the initial phases of this study, several approaches to the horizontal deflection amplifier required for ASUPT were briefly considered. The typical non-linear switched circuit commonly employed in television receivers with a yoke driving output transistor, transformer, damper-diode, linearity correcting capacitor, and similar components was considered; however, in view of the corrections required in the ASUPT system it was decided that a linear (i.e., Class AB Sub 1) amplifier should be employed. Further, it was concluded that a power supply switching operation should be employed to hold the power dissipation to reasonable limits. Parallel operation in preferred to obtain the high current capability because this can overcome the serious problem of very low current gain at high collector currents. Operation at reduced collector currents is necessary to achieve reasonable speed and high reliability.

Early in this study, a survey was made of transistor manufacturers to locate a suitable device for the horizontal deflection amplifier output stage. Many manufacturers were contacted, and the overall circuit problem was discussed. It is apparent that the most suitable solid-state devices available are those intended for H-sweep use in color television receivers; however, as was noted, the ASUPT application is far more stringent. Of all the firms considered, it appears that Delco Radio Semi-Conductor, Motorola, and Fairchild have devices which come the closest to meeting the requirements of the ASUPT CRT deflection amplifier. Delco was the apparent leader when they announced their DTS-802 and DTS-804 line about a year ago; however, now Motorola's MJ8400 and MJ9000 may be equal. At this time the most promising device appears to be Fairchild's PL108 which is not yet available for sale. It is a redesign of the Phillips BU-108 which Fairchild is making on license from Phillips.

Determination of power dissipation in the horizontal sweep is complicated and will depend on the exact form of the circuit used. The estimate below considers the worst case of a linear sweep circuit with no power supply switching. A switched power supply is recommended, however, and in the limit can reduce the power by a factor of 3 to 10.

> Yoke voltage, $E = L (DI/DT)$

tor

$$L = 70 \text{ microhenries}$$

and

$$I = +15 \text{ to } -15 \text{ amps.}$$

With the timing indicated in Paragraph 3.3.1.4.2, the power for the driver circuit active device is

$$P \text{ (forward)} = 1.77 \text{ kilowatts}$$

$$P \text{ (reverse)} = 422 \text{ watts}$$

or a total

$$P(T) = 2.192 \text{ kilowatts.}$$

Even assuming a full 100 watts dissipation/transistor, one must employ 18 in parallel for forward driver and 5 in parallel for the reverse driver. Since a switched power supply circuit is anticipated, it will not be necessary to operate so many in parallel; however, 4 to 6 in parallel are recommended to reduce the current/transistor to low limits to achieve a reasonable current gain and good time response.

3.3.2.5.4   V-Sweep

Assume the inductance of the vertical coil to be $L = 140$ microhenries. Interlacing blanking time is 11.5 (32.5 microseconds) = 374 microseconds. Compatible TV vertical blanking is nominally 8 percent of the V-time. Here, 0.08 (33 milliseconds) = 2640 microseconds so the interlace blanking is 1/2 or 1320 microseconds. Thus, the V-blank time selected for ASUPT is 3-1/2 times shorter than compatible TV blanking proportions.

From the above calculated forward time the forward voltage is

$$E_f = 4.2 \text{ volts}$$

and flyback voltage

$$E_{fb} = 14 \text{ volts.}$$

Forward Driver—Power Dissipation

$$\text{1/2 flyback, } P = 70 \text{ milliwatts}$$

$$\text{1/2 forward, } P = 120 \text{ watts}$$

Reverse Driver—Power Dissipation

$$\text{1/2 flyback, } P = 27 \text{ watts}$$

$$\text{1/2 reverse, } P = 0.75 \text{ watt}$$

With the timing indicated in Paragraph 3.3.1.4.3, the total vertical requirements are

Forward Driver, P = 120 watts

Reverse Driver, P = 30 watts

3.3.2.5.5 Screen Voltage

Nominal maximum average power is given as

$$P = (35 \text{ kilovolts}) (4 \text{ milliamps}) = 140 \text{ watts}$$

Using this figure and including the circuit dissipation with a small addition,

P (total) = 150 watts

.3.2.5.6 Electronic Components (Interfaces) Remaining

The total on platform power per channel associated with the interfaces defined in Paragraphs 3.3.1.1.2.4 to 3.3.1.1.2.15 with the exception of the Screen Voltage is 161 watts maximum.

3.4 ALIGNMENT STUDY

3.4.1 ALIGNMENT METHOD

3.4.1.1 General

It is recommended that initial electrical alignment of the individual CRT be done on a test stand without using signals from the computer and prior to insertion of the individual CRT in the motion platform location. A procedure for the alignment is given below in order to indicate the controls and control location necessary for complete alignment.

3.4.1.2 Individual CRT Alignment

3.4.1.2.1 Electrical

1. Each CRT is checked electrically separate from the image generator.

2. Adjust axial and angular position of all focus and deflect components.

    a. Adjust alignment coil—with little or no focus, and no other focus or deflect signals. Adjust alignment coil for symmetric unfocussed spot and maximize beam current

    b. Adjust centering coils—adjust centering to yield only spot shape change and no deflection of partially focussed spot as astigmatism is swept through entire range.

    c. Adjust focus coil (static)—set for best focus near center with reduced beam. Use AC waveforms to adjust mechanical coil location.

    d. Adjust raster center—check and adjust raster center with no deflection.

e. Adjust deflection yoke—apply deflection with nominal shading and distortion corrections. Set deflection yoke position for symmetric and minimum spot aberrations at field edge.

f. Adjust yoke orthogonality—rotate yoke to exactly align a single horizontal scan with a horizontal reference on CRT faceplate. Then with only a vertical saw apply orthogonality corrections to make the vertical scan coincide with a vertical reference on the CRT faceplate.

3. Setup Raster Geometry—The concept is to apply the analytical correction functions for basic raster geometry, namely the pincushion and CC/CD corrections, as though they were perfect. After adjusting H and V sweep size with an oscilloscope to the analytically determined value, use the other correction functions intended for distortion correction to provide the proper variation of the nominal H and V saw input to cause the CRT raster on the screen to coincide with some reference grid. The additional image distortion corrections will be designed so they do not alter the location of the spot at the four raster corners. Since the corners are blanked, raster size must be carefully set with the H and V saw input to the deflection system. When image distortion corrections are applied they bow the shape of a given test raster grid line, but not change the size of the outer corners of the grid. This method reduces the coupling of the raster corrections from raster size adjustments. Since the total useful raster (i.e., pentagonal define) does not extend to the corners, there will be some size change with raster image distortion correction, so it will be necessary to iterate at least once to correct the final raster size.

4. Apply Complete Raster Shading Corrections—After raster geometry is completely aligned set beam current to a nominal value and apply the shading corrections. First, apply the analytically determined corrections for barrel ASUPT raster, $\cos \phi$, and measure the result. Then apply the additional corrections to form a uniform brightness screen.

5. Apply Gamma Corrections—Use an electronic "staircase" input and measure result of screen brightness variations. Modify gamma correct to yield the most linear transfer characteristic. Measure small area and large area contrast before and after gamma correct.

6. Measure Resolution—After all corrections are applied measure resolution at grid points over screen. Check variation with beam current (brightness). Use an electronic resolution test object (three bar, Doyle chart or Sayce chart) and adjust focus both on a microscopic examination of the scanning spot as well as a subjective view of the raster at a distance near visual acuity limit of scan lines. Note any difference. Likewise modify vertical static astigmatism, while viewing inside the limit of scan line visual acuity and adjust for subjective image improvement.

7. Dynamic Focus—After complete resolution checks are made without dynamic focus corrections, impose dynamics and note improvement. Add dynamic focus first to obtain a uniform field. Check resolution and compare with former results. Next add dynamic astigmatism

and note improvement (if used). Last add dynamic focus (video) and note improvement of resolution using an electronic resolution object waveform modulated with a three level amplitude envelope. This will permit observation of high resolution data at peak, intermediate, and lowest brightness to insure preservation of focus.

8. Blanking—Set blanking defines with the aid of the pentagonal blanking circuit. Observe the unblanked raster. Set unblanked raster shape to coincide with some external reference mask or reticle.

3.4.1.2.2   Mechanical

The mechanical details of individual CRT alignment are at this point somewhat approximate. It is recommended that the CRT be mounted in a mechanical structure or enclosure which provides a complete package which can be adjusted as an individual CRT and then without disturbing any adjustment, be moved to the motion platform where it fits into a cellular mount behind a Farrand window. This mechanical package should be completely self-contained with all the electrical connectors, cabling, electronic components, cooling, electrostatic shielding, magnetic shielding, or other provisions to permit a complete transfer from CRT test stand to motion platform without affecting alignment.

3.4.1.3   Composite CRT Alignment

3.4.1.3.1   Electrical

It is recommended that the initial step of CRT alignment prior to insertion in the motion platform cell consist of joining the CRT with a nominal Farrand window to set up image distortion and window shading correction functions. Here electronic test signals from the CRT test stand are used to set up the required window corrections. It may be found necessary to provide a 1-to-1 correction of CRT to window to insure that each window is exactly corrected. This is a rather restrictive method and, thus, should be avoided if possible.

After the CRT systems are positioned in their cellular structure on the motion platform, all further alignment must be done in the cockpit of the simulated aircraft by viewing the CRTs through the windows. Removal of the aircraft wind screen would facilitate these alignment tests.

At this point a special alignment console is recommended which will be brought into the cockpit. It contains all necessary adjustment controls for seven CRT systems. Each CRT is aligned first for image distortion by applying the corrections provided. For this alignment some form of reference grid image must be provided superimposed directly on the CRT screen image viewed directly or superimposed with the aid of an optical instrument (i.e., a form of telescope).

Once the image distortion of the window is removed with CRT image distortion correction, the window shading is removed with CRT shading correction. This measure will first be done by visual examination, and final adjustment can be made with some form of photometer.

The final and most critical stage of alignment involves an iterative process to bring about a best fit between all the CRTs to effect a subjective impression of being surrounded by one single unsegmented display. Final alignment can be done in two stages. First the image distortion and resolution controls must be finely adjusted to give image continuity at the individual CRT image boundaries. This will be aided by employing an

73

electronic test signal which consists of a coarse grating and in selecting the H and V axes of each CRT system to choose an orientation which meets the observer's needs during normal simulator operation and which still permits a scan line test pattern that is continuous across the image joints. This orientation is illustrated with reference to Figure 32(a) which shows the front view of the composite window model. This would be the window the pilot looks out in his normal forward facing position. It is important to orient the raster lines such that they do not coincide with either the horizontal or vertical attitude reference planes. Thus, looking to Figure 32(b) the scan lines on his CRT channel would be best oriented parallel to one of the pentagon bases on the upper left or upper right. Assume the scan lines to be parallel to the pentagon base on the upper right. Now if the connecting pentagon on this parting line (window point) is considered to be one of the dodecahedron bases and the opposite pentagon the other base, then all CRT channels could be designed to operate with their scan lines parallel to these base pentagons. With the appropriate test pattern, this will then create for an observer inside the display a presentation of continuous lines running from one window to another. At the window display image joints there will be a discontinuity in the test pattern line attitude, which will make it easier to see image joints and aid in the alignment.

At this stage of composite alignment, all CRTs are on with a coarse raster test pattern. For instance, 50 scan lines on and 50 scan lines off yield 10 equally spaced bright bands for each display. The final image rotation can be accomplished while visually observing the display directly. Then the image distortion corrections are modified to yield image continuity across the joints. Starting at the forward facing window and correcting adjacent channels working outward, the display brightness and gamma correct will be adjusted to obtain some acceptable degree of subjective image continuity across channels. After resolution is checked and after iterations are taken with image distortion and shading, the last operation consists of adjusting the vertical astigmatism to just remove the scan line structure from obvious recognition.

3.4.1.3.2 Mechanical

The major mechanical requirement to be placed on the composite window alignment is that the CRT package when fitted into its cellular mount on the dodecahedron structure is perfectly aligned in the physical location. This will provide mechanical entering, angular position, and focus for the CRT screen in the window focal plane to within the optical requirements of the window.

3.4.2 HARDWARE DEFINITION

3.4.2.1 Individual CRT Alignment

The electronic test equipment will include video dot, bar and raster generators, H and V sync and ramp generators, monitor scopes, and voltage and current meters. The CRT electronics will be that used in the final system. The alignment and test procedures will be designed so that many of the adjustments can be made using electronics test monitors instead of requiring CRT monitoring at the faceplate for initial stages of alignment.

3.4.2.2 Composite CRT Alignment—Electronic Test Equipment

A more complex electronic video pattern generator will be required for composite CRT testing. Its principal function is to facilitate geometric edge matching of adjacent CRT rasters. A coarse raster, first 50 lines on, 50 lines off, then a finer 10 lines on and 10 lines off, will be generated on all CRTs so that continuous horizontal bands appear to encircle the viewer. When the CRT deflection circuits are aligned properly, there

74

a. Front View
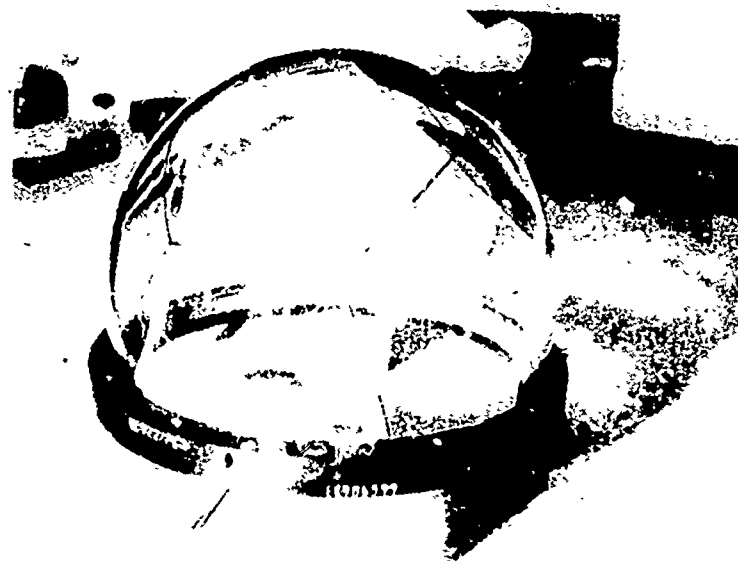
b. Side View

Figure 32. Composite Window Model

will be no discontinuities in the bands at the CRT edge interfaces. The pattern generator will also produce vertical bars to align the top CRT with the system. Other patterns may be included if needed.

3.4.3 TEST, ALIGNMENT, AND OPERATIONAL PROCEDURE

3.4.3.1 General

The CRT electronics equipment will be designed to facilitate the periodic test, alignment, and maintenance of the display system. This design shou'd include a built-in test pattern generator, adequate test points for monitoring voltage levels and wave shapes, and the ability to replace and align any component.

3.4.3.2 Individual CRT

There are two options in the alignment and test of the individual CRT. In the first the CRT remains in the composite CRT assembly. In the second, it is removed and mounted on the CRT test stand. In either case the test procedure is as follows:

1. Electronic

   a. Check all voltage and current levels for variations from nominal.

   b. Monitor the wave shapes of the function generators, analog computers, and power amplifiers comparing them with expected shapes.

2. Spot

   a. Measure the spot size and shape.
   b. Check for variations across the raster.

3. Raster Geometry

   Measure the raster:

   a. Size.
   b. Position.
   c. Rotation.
   d. Orthogonality.
   e. Distortion.

4. Raster Photometry

   Measure the raster:

   a. Luminance.
   b. Shading.
   c. Gamma.
   d. Contrast.
   e. Grey shades.

Use the test reticle for raster alignment if the CRT has been removed or use the uniforn grid projector if the CRT remains in the composite system.

76

3.4.3.2 Composite CRT

The composite display system is periodically tested for image geometry discontinuity by displaying a generated test bar pattern which can be electronic or computer generated. If the discontinuity is out of tolerance, then the defective individual CRT systems must be aligned. The test for photometric discontinuity 's made by generating a uniform luminance raster and noting discontinuities visually. If the discontinuity is noticeable, then its value can be measured using a brightness meter.

3.5 CONCLUSIONS

Based on the data inputs from Thomas Electronics, test data on the ASUPT CRT, and the preceding analyses, it is concluded that the brightness and resolution requirements are feasible. Analysis of the test CRT at 4 milliamps peak beam current shows it would produce an ASUPT display brightness of 4.16 footlamberts. Thus, unless Farrand window transmission is increased, the beam current must be increased to 5.77 milliamps to achieve a 6 footlambert display brightness.

Resolution of the test CRT is adequate to meet the transverse spot requirements, but the radial spot size exceeds system requirements in the region of 30 to 40 degrees field angle, by the amount shown in Figure 18.

A specific choice of focus and deflect components should be made based on experimental verification. Since the present resolution test data was obtained with a high inductance yoke, this data should be retaken with the yoke which is finally selected.

More complete test data is required on the CRT spot size versus beam current at beam currents of at least 6 milliamps. Over a range of field angles using the final choice yoke, experimental tests should be run to determine the characteristics of the focus (video) requirements.

In view of the test CRT resolution performance, it is essential that the final ASUPT CRT employ a deflection half angle no larger than 35 degrees. Further, the tube neck length must be sufficiently long to adequately accommodate the required focus deflect components.

There is a need to redesign the CRT cathode lens for better life and lower drive requirements. Initial study indicates 150-volt video swing is within state-of-the-art at 20 to 40 MHz, but the requirement of 200 volts swing will require additional work and will involve much higher power vacuum tubes.

The CRT should be mounted in a self-contained enclosure or package which can be moved from the CRT test stand to the motion platform and be located exactly to within required limits by mechanical references.

The electronic signal parameters including specifically regulation and stability are approximate and require a perturbation analysis to determine final performance requirements.

Totals of the most important physical parameters for the platform-mounted CRT electronics are listed below:

a. Total summary platform mounted electronics (maximum estimate)
(for each CRT system)

Size	4.085 cubic feet
Weight	324 pounds
Power-Cooling	4.749 kilowatts

b. Total summary platform electronics (maximum estimate)
(for total system)

Size	28.6 cubic feet
Weight	2,268 pounds
Power-Cooling	33.24 kilowatts

c. Total summary CRT mounted electronics with remoted power supplies for H and V sweep, video, and split-screen voltage supply
(for each CRT system)

Weight	144 pounds
Power-Cooling	3.26 kilowatts

SECTION IV

CRT ELECTRICAL CHARACTERISTICS

4.1 INTRODUCTION

4.1.1 PURPOSE OF STUDY

This report documents the results of an investigation directed toward the definition of primary design and performance parameters for a unique cathode ray tube designed specifically to interface with an In-Line Infinity Optical Assembly (pancake window) This CRT electrical characteristics study program was conducted by Thomas Electronics, Inc., under subcontract to the General Electric Company. Because of the significant impact of the CRT characteristics on both the image generation and flight simulator interfaces, further definition of the CRT design parameters was required. Certain CRT design constraints and requirements are fixed as a result of the ASUPT specified optical and image generation configurations and overall system requirements. This report describes the results of the investig. .on and analysis which were required to establish feasible CRT characteristics consistent with the ASUPT requirements.

4.1.2 SCOPE

The CRT required for the ASUPT visual simulation is unique in that it substantially exceeds in diameter, screen area, and total luminous emission, any cathode ray tube hitherto developed. Earlier visual display systems for the Apollo Mission Simulator and the Air-to-Air Combat Simulator system provided a basic design background.

The investigation emphasized the building and testing of special experimental CRTs that incorporated design features very closely approximating those required for the final CRT in order to obtain data on key parameters which are accurately representative of ultimate performance. The effort also included analytical studies covering other significant parameters.

4.1.3 APPROACH

The study program was organized to investigate all relevant parameters following established guidelines in CRT design studies. The categories of parameters included in the task were:

      a.   Physical and mechanical.
      b.   Electrical.
      c.   Brightness and optical performance.
      d.   Life.

The parameters are discussed in the following sections and are referenced to the appropriate CRT characteristics.

4.2 CRT ENVELOPE DESIGN

An all-glass envelope design and corresponding bill of material were anticipated at the commencement of the CRT study, and confirmation of vendor sources has been established for the procurement phase. Non-browning faceplace glass in the form of ground and polished discs to satisfactory blemish specifications is available both from

Schott Optical Glass Company (Glass No. 3459) and Corning Glass Works (Glass No. 9025). A two-piece spun glass funnel in 0120 glass can be produced in the Radome facility of Corning to satisfactory mechanical and quality specifications. The faceplate and funnel can be sealed by the frit technique as proven in CRTs for earlier Air-to-Air and Apollo Visual Simulator programs. However, continued investigations into cost, lead time, and safety factors have resulted in two alternative approaches to envelope fabrication.

It appears feasible to sag the rear funnel section from plate glass by the same technique employed for faceplate sagging. By employing a commercial plate glass for both faceplate and funnel, together with an appropriate conical neck and fla   -ection sealed to the sagged funnel component, it is possible that the entire CRT enve   could be produced at substantially lower cost and within a 90-day delivery period.   irther investigation into the availability and properties of commercial plate glass is underway to confirm feasibility of this envelope fabrication approach.

An important consideration in producing an all-glass envelope employing either a spun or sagged funnel component relates to the potential implosion hazard presented during the CRT processing operations. A particularly vulnerable phase of processing occurs between the CRT evacuation step and the application of implosion cap and funnel shields. Implosion precautions necessary during this phase would be greatly simplified through the use of a metal funnel envelope component. The feasibility of adopting a metal funnel design has therefore been re-examined.

Prior practice with metal funnel CRTs has involved the use of a hot sealing technique for the faceplate. This technique is highly critical and requires special annealing equipment. The use of a pyroceramic frit technique for sealing the faceplate to a spun metal funnel appears quite feasible and could result in substantial cost and time savings, in addition to providing a CRT envelope which is inherently less hazardous during both processing and end use.

4.3 CRT ELECTRICAL PARAMETERS

Two special CRTs have been constructed and evaluated to provide electrical performance data. Both tubes employed a 19-inch diameter faceplate sealed to a low deflection angle funnel similar to tube type 19M34 which closely approximates the funnel length of the 36M10 ASUPT CRT. The first tube employed a conventional on-axis gun/neck assembly. At 35 kv, it exhibited the following characteristics on-axis:

Modulation Voltage (VDC)	Anode Current (Microamperes)	Line Width (Inches)
20	17	0.010
40	130	0.012
60	390	0.018
80	900	0.020
100	1830	0.022
120	3300	0.030

The second tube was fabricated with the gun/neck assembly inclined to result in undeflected spot landing near the CRT screen edge. The maximum deflection angle of the beam across this CRT screen is 40 degrees as in the presently configured 36M10 ASUPT tube. The off-axis line width data was taken at a 35 degree deflection angle.

This off-axis line width data is, therefore, fully representative of that obtainable in the final CRT. At 35 kv, the following data was obtained:

Modulation Voltage (VDC)	Anode Current (Microamperes)	Off-Axis (35 Degrees) Line Width (Merged) (Inches)	Brightness* (Footlamberts)
20	22	0.010	6.5
60	250	0.018	145
100	1050	0.024	530
120	1600	0.026	700
140	2800	0.028	970

The deflection coil employed was a Syntronics type Y66EFGS. The focus coil was type JEDEC Standard No. 122 manufactured by Rola Corporation. The writing rate was 600,000 inches/second with a line spacing of 20 lines/inch.

It will be noted that the off-axis line width is essentially comparable to the on-axis performance within the limitations of the modulation level of 140 volts, which in the case of the second CRT resulted in a 2.8 milliamp beam current. Due to video pulse amplifier limitations, it was not possible to operate the off-axis CRT at modulation levels above 140 volts. To determine, therefore, whether line width increased sharply at the 4 milliamp level, a brief visual observation of raster lines was made with the grid setting adjusted to provide a 4 milliamp beam current at dc level. No excessive line width growth was observed during this subjective evaluation.

The Syntronics Y66EFGS deflection coil is a high inductance type, and in general, deflection defocusing is increased with the low inductance coil designs; however, Dr. H. O. Marcy, the deflection coil consultant in this study, states that comparable performance should be obtainable from a deflection coil with reduced inductance, on the order of 100 µh, suitable for the CRT electronics design.

The deflection coil diameter of the Y66 yoke is 2.125 inches. The excellent off-axis line width readings can be partially attributed to this larger-than-normal yoke diameter. The favorable readings, however, suggest a possibility that a standard 1.5-inch yoke may be feasible, thus simplifying deflection amplifier design. The off-axis CRT will be retained for future yoke testing.

The X-radiation emerging from the 0.35-inch thick CRT faceplate during operation of the on-axis CRT at 38 kv and with 1 milliamp dc beam was 18 milliroentgens per hour at a 6-inch distance from the faceplate. However, the insertion of a 3/16-inch thick implosion panel between the CRT faceplate and the radiation survey meter reduced the X-radiation to less than 0.1 milliroentgen. It should be further noted that the anticipated faceplate thickness of the 36M10 ASUPT CRT is 0.6-inch minimum, which is approximately twice that of the 19M34 CRT. The X-radiation emerging at higher beam currents is directly proportional to the X-radiation data at 1 milliamp, so that twice the beam current results in twice the X-radiation.

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*At 600,000 lps with 20 lines per inch.
Phosphor type — P20.
Luminous efficienty — 40 lumens/watt.

4.4 OPTICAL CHARACTERISTICS AND SCREEN BRIGHTNESS

The selection of an optimum phosphor screen with emission characteristics matching the transmission properties of the pancake window has been investigated in the light of current progress in pancake window construction. A recent window spectral transmission curve exhibits a peak zone over 5,000 to 5,800 angstroms, with a particularly sharp falloff below 5,000 angstroms. The use of a white P-4 screen consisting of a blend of blue and yellow phosphors would appear to be most inefficient, and even the choice of a high-efficiency P-31 would appear questionable in view of the significant portion of P-31 energy emitted below 5,000 angstroms. The best choice at present appears to be a P-20, peaking at approximately 5,450 angstroms. (See Figure 33.)

In addition to the direct transmission match requirement, there are, however, other considerations in the pancake window design which raise further phosphor selection questions. For example, the use of a very narrow band phosphor, such as P-44, would assist in the accurate alignment of pancake window components, but may accentuate transmission uniformity problems associated with quarter waveplate uniformity. It is probable that the intensity and color of ghost images could be affected, and possibly minimized, by the use of a phosphor with low side-band emissions. It would appear that blue emission content or side-band peaks would be particularly objectionable since most bleed-through appears to be in the blue portion of the spectrum. All of these questions of course, must be considered in relation to both on-axis and off-axis properties of the phosphor/pancake window match.

At the present time, it would be premature to suggest a specific phosphor in view of detailed material and design factors concerning the construction of pancake windows currently underway. Close liaison with Farrand Optical engineers is recommended to arrive at an optimum selection, as final pancake window characteristics are established.

It should be noted from Paragraph 4.3 that an area brightness of 950 footlamberts was measured on the off-axis experimental CRT under the conditions specified. This measured brightness reading corresponds very closely with the calculated screen brightness assuming a phosphor efficiency of 40 lumens/watt, which is a typical figure for high-efficiency sulfide phospnors operating at high brightness levels. Assuming that a high-efficiency sulfide phosphor similar to P-20 will be acceptable as an optimum transmission match, it will be noted that an increase in beam current of up to 6 milliamp, or a correspondin- power increase in beam current and high voltage ratio, will be required to provi : a field brightness of 1,000 footlamberts at a writing rate of 1.2 million inches/second.

The actual writing rate may be somewhat faster than this, but the line spacing of 20 lines per inch may be only a worst case maximum spacing condition at the extreme center with a substantially increased average line density over most of the screen area. A precise calculation of beam power required for sufficient screen brightness is not practical until further details are available concerning the non-linear-raster characteristics and retrace blanking ratios. It is also not possible to state at this time the net pancake window transmission with its matching phosphor screen. It would appear, however, that the use of the most efficient sulfide-type phosphor would be highly desirable in view of the high beam power requirement.

In the testing of the off-axis CRT, no subjective variation in color of the P-20 phosphor screen was apparent up to the 970 footlamberts level attained. Since P-20 is a single peak phosphor, in comparison with the double peak characteristic of P-31 for example, it is not anticipated that significant color variations will occur either initially or during the life of the phosphor screen. To establish repeatability of color on successive CRTs, it is recommended that a substantial quantity of the P-20 phosphor be procured

and stocked for use over the anticipated life of the program, since this class of phosphor is both inexpensive and has an extremely stable shelf life.

In view of the favorable line width results reported in Paragraph 4.3, small area contrast ratio, or MTF, should be relatively high, but quantitative measurement is not practical without a more detailed definition of raster design. Large area contrast ratio at 1,000 footlamberts was 200: 1 on the off-axis CRT (from a measured background value of 4.9 footlamberts 1 inch away from edge of raster at 1,000 footlamberts of area brightness).

4.5 ANTICIPATED TUBE LIFE

The tubes fabricated for life test incorporated 19 inch 90 degree envelopes, since life test equipment was readily available for this CRT size. The guns employed were similar to the 27M23P-type (Air-to-Air CRT) which, in turn, was derived from the 27M18P-design, which has demonstrated an average life of 12,000 hours in use on the Apollo Mission Simulator. The 27M23P-gun design was also employed in the 19 inch low-deflection angle CRTs in the line-width and brightness studies above. It was anticipated that this design would be suitable for the proposed 36M10P CRT, with a cut-off adjustment to provide a 4 milliamp capability. The cathode loading factor in the gun triode section is approximately 1 amp/square centimeter. No special processing steps were taken in the fabrication of the 19 inch life test tubes; 75 mgm. S.A.E.S. exothermic getters were employed. The phosphor screen was P-31; the acceleration voltage employed during the test was 15 kv. Although this voltage is lower than the screen acceleration voltage recommended for the ASUPT CRT, it is valid to use a lower voltage in this test since the test is primarily directed toward examining cathode behavior. The tubes were operated on a dc basis with a fully scanned raster and were monitored once weekly. Six tubes were originally fabricated, but one tube exhibited a leakage path during initial test and was, therefore, unusable. Due to the fixed time available for the life test study, it was not practicable to build an additional tube to replace the rejected one. The final life test results were as follows:

Tube No.		1	2	3	4	5
D/C Beam Current:		1.0 ma	2.0 ma	1.0 ma	1.5 ma	2.0 ma
Percent of Original Emission at:	477 Hrs.	96	113	86	92	92
	1009	128	70	57	51	—*
	1491	96	51	38	51	—

*CRT total loss

It will also be noted that Tube No. 5 was lost after the first 477 hour test measurement. This tube developed a neck crack resulting in loss of vacuum. The origin of the crack was ascribed to a handling bruise which occurred during removal and insertion of the CRT in the test equipment associated with the life test rack.

All five tubes exhibited a satisfactory emission level at the 477 hour test point (nominal 500 hours). One tube in the group continued to operate at a high efficiency level throughout the 1491 hours of test (nominal 1500 hours).

84
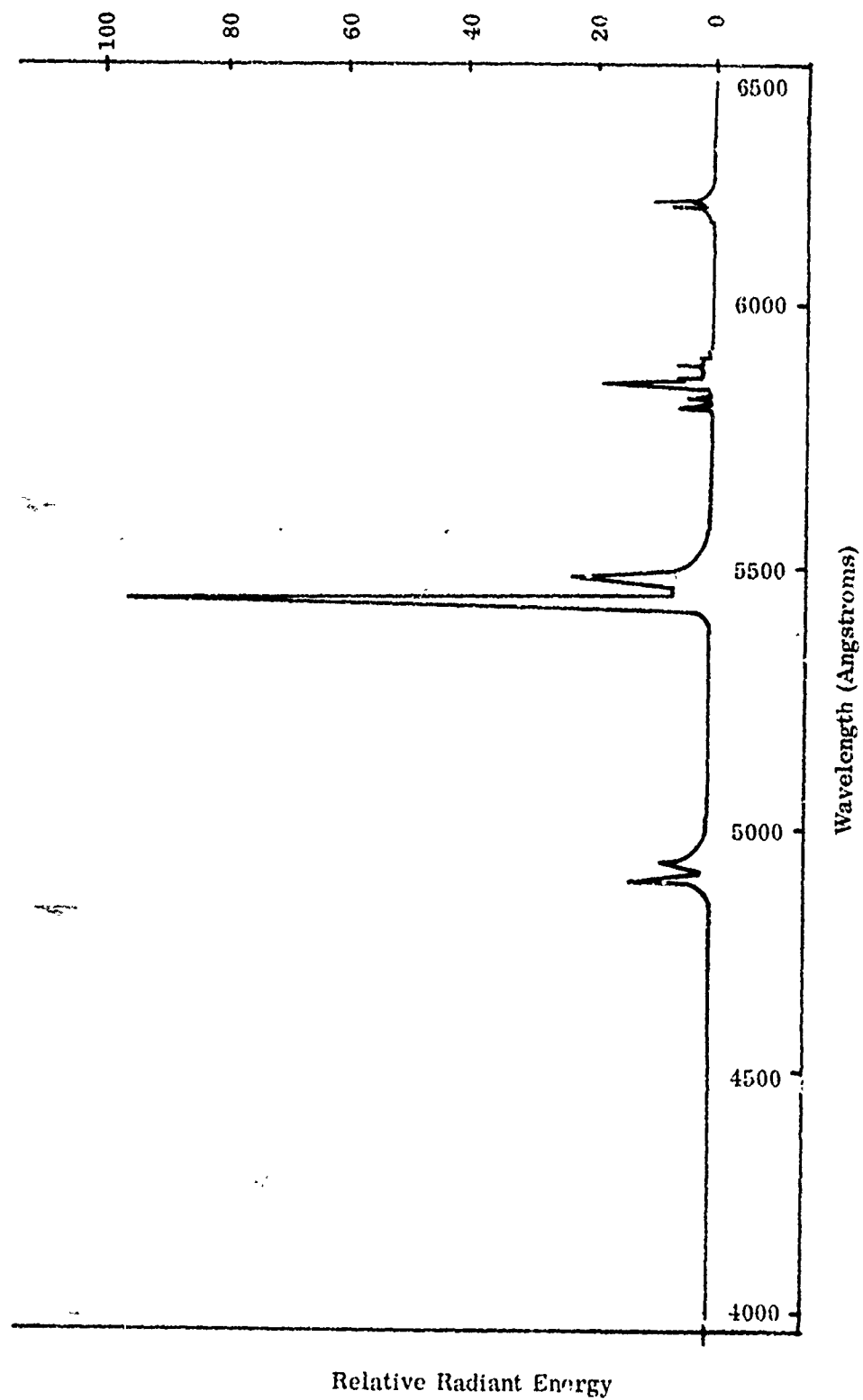
Figure 33. ASUPT/Cathode Ray

The tubes were examined at the completion of the test period with the following results:

Tube No.	Serial No.	Getter Mirror	Cathode Condition
1	34523	Darkened but intact	White (normal)
2	34529	Non-metallic	White (thinned)
3	34530	Non-metallic	Greyish (thinned)
4	34521	Non-metallic	White (normal)

General comment: Cathode ceramic — no sublimation.

The depletion of the getter mirror in an electron tube is a strong indication of excessive outgassing of tube coatings or electrodes in operation. It would appear that the degree of outgassing, presumably from the phosphor screen at the high dc beam current levels in the test CRTs, was substantially higher than normal and resulted in early getter depletion in three of the tubes during the test period. To provide an operational life time for the proposed 36M10 CRT more nearly comparable to that of a conventional tube, it would appear necessary to incorporate getters with larger yields and to extend the outgassing time temperature cycles during final CRT evacuation. This latter requirement will be fulfilled as a matter of course during the processing of the 36M10 bulb since a 24-hour time-temperature cycle similar to that employed in the 27M23 and 27M18 CRTs will be necessary for thermal gradient requirements.

The calculated life of a sulfide phosphor screen such as P-20 or P-31, assuming a 20 coulombs/square centimeter half brightness characteristic, is 10,000 hours at a dc beam current of 1 milliamp. A final prediction of tube life limitation due to phosphor screen aging cannot be made until the phosphor choice is known and until operational brightness levels established. However, it would appear that a substantial margin is available.

4.6 CRT SPECIFICATION

Based on the investigation and results of the study, a CRT specification was prepared and is included in the attached Appendix f.

4.7 CONCLUSION AND RECOMMENDATIONS

The results of the CRT study appear to be most encouraging and confirm the "anticipated results" in that an acceptable minimum performance level has been demonstrated. The envelope design aspects are especially favorable in view of the options and alternatives which are now available. With the choices now established, there appears no doubt that satisfactory envelopes can be fabricated. The anticipated weight of an all glass envelope is estimated to be 200 pounds.

Screen brightness and resolution results indicate that with an increase in beam current of up to a maximum of 6 milliamp, adequate resolution should be available at a 1,000 footlamberts area brightness level; however, if additional development and study confirms the need for 6 milliamp peak currents, it would appear highly desirable to develop a gun design which would require reduced video drive since to achieve a 6 milliamp beam current with a conventional triode section, a minimum of 200 volts of video signal would be required. High transconductance techniques exist which could probably reduce video requirements by a factor of between 2 and 5, and it is recommended that additional study and development be conducted to verify the feasibility of such designs in this application, with particular reference to preservation of adequate resolution.

Adequate options appear to exist with regard to selection of an optimum phosphor screen. A final choice is unlikely to require any new materials development.

The results of the life test study suggest that a continuation of study and development is required to confirm the tentative conclusions. Additional tubes should be built employing the largest available envelopes and incorporating increased getter yields and extended exhaust processing. With this additional development work, it is considered probable that the 36M10 life can be predicted at between 5,000 and 10,000 hours.

SECTION V

DISPLAY MULTIPLEXING

5.1 INTRODUCTION

5.1.1 GENERAL

The goal of the display multiplexing task was to establish the feasibility and practicality of multiplexing two cockpit displays from the single ASUPT image generation system and to scope the impact on the basic system design. The flexibility of the image generation system would be enhanced if it could service two flight simulator/display stations operating in independent modes. Furthermore, if such multi-display drive capability could be obtained by a hardware increment to the basic system, cost effectivity also would be improved.

The determination of this feasibility and practicality was achieved by the implementation of two parallel investigations on (1) System Organization and Hardware Requirements (Paragraph 5-2) and (2) Motion Discontinuity Effects (Paragraph 5-3). The system organization and hardware requirements investigation has been directed toward the assessment of two technical approaches to providing a display multiplex capability, their combination in a dual mode, and the definition of organizational and hardware modification (and/or increments) to implement these approaches. The three approaches were:

    a.   Time-multiplexing, when full edge capacity is provided to both display groups, but scene update rate is reduced.

    b.   Edge capacity multiplexing, when update rates for both display groups remain at 30 updates per second, but predetermined portions of the total computational capacity are allocated to each display group.

    c.   Dual multiplexed mode, wherein both the time and the edge capacity multiplexed capabilities are provided for selection by the system operators.

5.1.2 SUMMARY

5.1.2.1 System Organization and Hardware Requirements Investigation

This investigation was made to determine the feasibility and implementation approaches for incorporating a time-multiplexed, edge capacity-multiplexed, or dual mode multiplexed capability into the basic ASUPT visual system.

To make this determination, an assumed set of system requirements was established and documented. From the requirements, an analysis was made to assess the functions that would be impacted by the addition of each of the display multiplexing capabilities. Further study defined the impact the hardware and software modifications would have on the basic system.

In summary, the investigation proved from the system configuration and implementation aspect that time multiplexing, edge multiplexing, or both capabilities are feasible and a practical approach exists in each case. The decision to add a multiplexing

capability to the ASUPT visual system is essentially a tradeoff of cost versus training capability including consideration of the motion discontinuity effects investigation.

5.1.2.2 Motion Discontinuity Effects Investigation

This investigation was made to determine the feasibility of incorporating a time-multiplexed capability into the basic ASUPT visual system. The crux of the problem was basically a subjective evaluation of the system degradation as a result of reducing the update rate from 30 to 15 times per second. Because of the subjective nature of this evaluation, a video tape was made to provide visual documentation of the results.

Upon completion of the investigation, it was found that motion discontinuity effects were more prominent in maneuvers requiring high-pitch, roll, and yaw rates (e.g., acrobatics). The higher the rates (above 20 degrees/second), the more objectionable the motion discontinuity effects.

In summary, it appears that this capability should not be considered as an option unless a significant portion of the training program is dedicated to the more routine manuevers (e.g., takeoff, approach, landing, and high altitude level flight) where the motion discontinuity effects are minimal.

5.2 SYSTEM ORGANIZATION AND HARDWARE REQUIREMENTS INVESTIGATION

5.2.1 SCOPE AND APPROACH

The system organization and hardware requirements investigation has been directed toward the formulation and evaluation of feasible technical approaches to provide a display multiplexing capability in the ASUPT visual system and the definition of organizational and hardware modification (and/or increments) necessary to implement these approaches.

This task was initiated by the generation of an ASUPT Computer Generated Image (CGI) Multiplexed Display Requirements Document which delineates an assumed set of requirements to guide the study. The only purpose of this document is to define the assumed multiplexed operational modes, system interfaces, essential operator functions, and related performance requirements that would pertain to the addition of a multiplexed operational capability to a basic, non-multiplexed operation ASUPT visual system. This document is included as Appendix II to this report.

The investigation was structured to assess first the functional impact of each mode upon the three major operational areas of the visual system. These are the general-purpose computer subsystem operations, the system interface operations (focal point for consideration of all instructor/operator stations), and the image processor operations. The detailing of these functional impacts was followed by defining the resulting additions and/or modifications required to the basic system in terms of software and hardware.

5.2.2 CONCLUSIONS

From the system configuration and implementation aspect, a feasible, practical approach exists in each case for the incorporation of a time-multiplexed, edge capacity-multiplexed, or dual-mode multiplexed capability into the basic ASUPT visual system. Block diagrams of the system illustrating each capability are given in Figures 35, 36, and 37. The investigations indicate no critical or significant development problems in attaining these additional capabilities. Estimated additional costs and schedule impact (if any) incurred in adding each capability are submitted separately from this report.

88

The decision to add a time-multiplexed mode capability to the visual system would appear to be based primarily upon evaluating its cost impact against the potential increase in facility utilization (allowing concurrent and independent operation of both cockpit/display stations) and any impact on training problem effectiveness. Consideration must be given to the adverse effects of motion discontinuity at reduced update rates as discussed in Paragraph 5.3. The seriousness and criticality of these motion discontinuity effects are amenable only to subjective evaluation and decision by those who will prepare and conduct the training activities planned for this ASUPT facility.

The decision to add an edge capacity-multiplexed mode capability to the visual system would appear to be based primarily and similarly upon evaluating its cost impact against the increase offered in facility utilization and any impact on training problem effectiveness. The basic constraint in this mode is that the total system environment display capacity must be proportioned between two problems to provide two displays of reduced scene content; however, motion rates are not reduced in this mode. The suitability of proportioned paired-problem operation in this mode is dependent upon the intended operational use of the system and on the acceptability of reduced scene content for various elements of the research program when operating in the dual cockpit configuration. Considering the motion discontinuity effects inherent in the time-multiplexed mode, it would appear that the edge capacity-multiplexed mode is a more favorable approach.

The constraints and possible limitations of these individual multiplexing modes must be evaluated in total for a dual-mode multiplexed capability. The decision to add a dual-mode multiplexed capability (as assumed in the requirements document) would appear to be based primarily upon evaluating its additional costs (over and above those of each individual mode) against the benefits from having both modes of multiplexed operation available.

5.2.3   BASIC ASUPT SYSTEM OPERATION

5.2.3.1   General

The basic ASUPT visual system configuration, as shown in Figure 34, represents the non-multiplexed display operation of two cockpit/display stations under control from instructor/operator stations. In this configuration non-multiplexed operation refers to the operation of either one of the two simulator station displays with a single simulation problem. This mode of operation designated the "individual" mode will allow up to the total system edge capacity operating at normal scene refresh and update rates of 30 scenes per second to service the selected station; however, the addition of switching to provide this required station select capability leads to the consideration of a second and closely allied mode of operation.

This second mode designated the "master-slave" mode will provide operation of either one of the two cockpit display stations in the individual mode with the other station acting as a slave to receive the same display presentations. This latter operational mode would allow an instructor or second trainee to sit in the second station and experience the visual cues and possibly the motion cues generated and experienced by the first cockpit station operator.

This feature requires only the gating of the non-multiplexed simulation problem (for visuals) to both stations in parallel since each cockpit station must have its own complement of display electronics and optics for the individual mode of operation. This feature is of insignificant hardware impact; therefore, non-multiplexed operation is
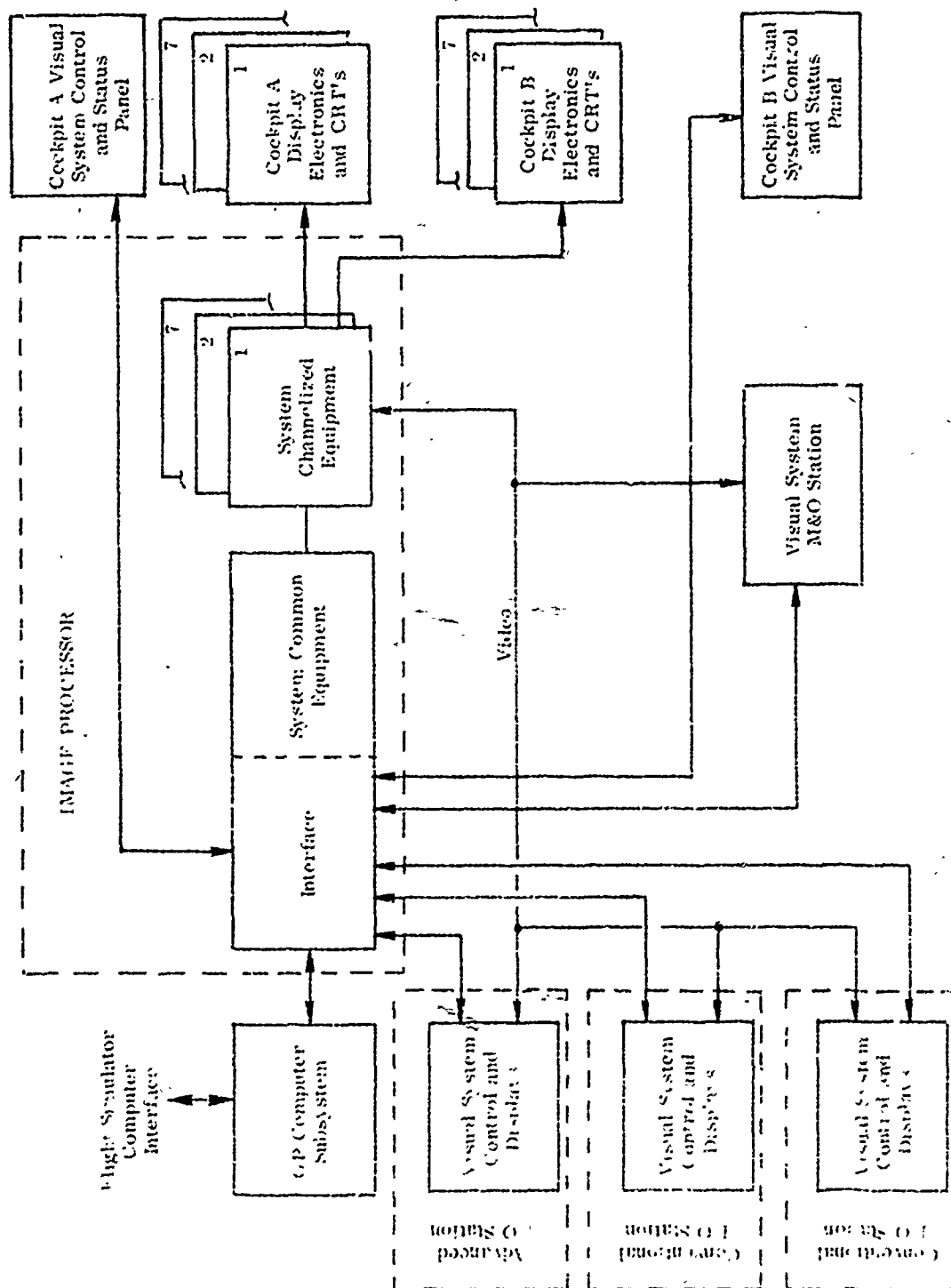
Figure 34. ASUPT Visual System Block Diagram—Basic, Non-Multiplexed Operation Configuration

90

defined to include the capability for operation in the "individual" mode or in the "master-slave" mode.

In addition to this switching function, the basic ASUPT system configuration is defined to provide the control and display interfaces and functions required for the advanced conventional, and cockpit instructor/operator stations. Since the individual mode requires only one station operation, the system design should provide for separate ac power control of the display electronics at the second station for power conservation and/or non-powered maintenance activity. This control may be accomplished from the advanced instructor/operator station, the visual system maintenance and operations station, or from a remote location at the equipment depending upon final ASUPT system requirements.

5.2.2.2   Computer Operations

General-purpose computer processing operations in the non-multiplexed visual system involve both off-line operations and on-line operations. Frame invarient, off-line operations performed within the general-purpose computer involve the following functions:

      a.   Preparation and formatting of environment data bases.

      b.   Program assembly and debugging to aid in initial system implementation and to provide for future system modification.

      c.   Software diagnostic provisions to check out the computer, image processor, and display subsystems.

Standard computer vendor-supplied diagnostic programs will provide diagnostic and checkout activities on the computer system. Special off-line visual system diagnostic programs operated in the individual and master-slave, non-multiplexed modes will accomplish testing and checkout of a majority of the system's image processor and display hardware.

Frame invarient, on-line operations involve the following functions:

      a.   Initialization of the on-line processors prior to mission start-up.

      b.   Responding to various interrupts—an instructor/operator station, for example. Such an interrupt could be a command to freeze the scene at a specific point so the instructor can highlight details to the student or possibly an interrupt to initiate a playback of a particular mission sequence.

Frame dependent, on-line functions are, in general, those functions which must be repeated each frame time to obtain the display scene for that frame. For many controlled movement cases, certain of the functions may be repeated at a constant multiple of the frame rate.

An executive program will provide the required integration and bookkeeping necessary to control and sequence the application each frame time of the various on-line functional programs which use the 30-per-second data entries and the given problem's environment data base. These functional programs provide for handling such representative functions as flight simulator input data scaling, aircraft relative position and attitude computation, coordinate transformations, special effects computation, active environment extraction, environment processing, interrupt response, data transfer, etc.

Basic environments composed of clusters of terrain and man-made features overlaid on a planar surface extending over a 512-square-mile area will be modeled and supplied with the visual system. During setup for a simulation problem, the total environment to be used would be transferred from magnetic tape to computer subsystem storage.

5.2.3.3   System Interface Operations

The basic ASUPT visual system will have external data and control interfaces with the flight simulator computer subsystem, the advanced instructor/operator station, two conventional instructor/operator stations, and two cockpit instructor/operator stations. For the purpose of discussing related interface operations in this section, the processing system interface with a visual system maintenance and operations station is included.

Subject to detailed system definition of the exact functions to be required and provided, the following visual system control and display functions at the advanced instructor/operator station are envisioned:

      a.   Status and confidence indications of system equipment readiness.

      b.   Program status and operating data indications relating to the visual display program being run (i.e., system edge capacity overflow, program running-time, etc.).

      c.   Specific action or program entry switches (such as for "record," "program freeze," and "program rerun," etc.) that are integrated with corresponding flight simulator system controls.

      d.   Two CRT display monitors with which to select any two channels of seven channels of the particular cockpit/display station being operated in the non-multiplexed modes.

The primary function of each conventional instructor/operator station will be limited to the conduct and monitoring of a training problem on a given cockpit/display station. It is envisioned that their visual system control and display functions would be limited to those four functions given previously for the advanced instructor/operator station. Equipment readiness indications might be limited to a critical subset of those indications provided at the advanced station.

It is assumed that the control and indication functions at the cockpit instructor operator stations will be further limited to those programs status indications associated with the given cockpit/display and to those program entry provisions enumerated earlier.

A visual system maintenance and operations station will be provided as an independent means of visual system operation to support display program development and maintenance and diagnostic activities. It will include all the control and display functions that are provided at the advanced instructor/operator station. It will provide any additional equipment status, confidence, and operation indicators and controls that may be required to support its primary function of system maintenance and diagnostics. Where system operation control functions are provided at both stations for either non-multiplexed or multiplexed operation this station will provide a required source control switch which assigns the control from these control functions to either one station or the other. Equipment power on-off control will be provided at this station unless this function is reserved to a remote location at the equipment.

5.2.3.4 Image Processor Operations

The image processor subsystem consists of that necessary special-purpose equipment which completes processing of the environment data received from the general-purpose computer subsystem. Its final outputs are the display signals in video form that are suitable for driving the seven-channel CRT displays in each ASUPT cockpit/display station. This subsystem is composed of system common equipment which is independent of the number of display channels required and of system channelized equipment which would be duplicated seven times for a seven-channel ASUPT display system.

The system common equipment consists of a group of equipment to process the environment with the results of these processing operations brought together in the channelized equipment to provide the composite detail in each frame's scene for each channel.

5.2.4 MULTIPLEXED SYSTEM OPERATION

5.2.4.1 Definition

The system organization and hardware requirements portion of this study is based upon the Multiplexed Display Requirements Document which delineates the assumed multiplexed operational modes, system interfaces, essential operator controls, and related performance requirements that pertain to the addition of a multiplexed operational capability to a basic, non-multiplexed ASUPT visual system. This document is included as Appendix II.

The two modes of multiplexed operation which are investigated separately are those of time-multiplexing and edge capacity-multiplexing, respectively. The time-multiplexed mode of operation will provide for concurrent, independent operation of two station displays with each display capable of utilizing the total system edge capacity at a 30 scene-per-second refresh rate and a 15 scene-per-second update rate. The edge capacity-multiplexed mode of operation will provide for concurrent independent operation of two cockpit displays at scene refresh and update rates of 30 scenes per second wherein the total system edge capacity is allocated between the two cockpit displays as determined by an instructor/operator.

The Requirements Document defines the multiplexed operational capability to require both possible modes of display multiplexing in the system. Per this definition, multiplexed system operation provides operation either in a time-multiplexed mode or in an edge capacity-multiplexed mode as selected by a system instructor operator.

5.2.4.2 Technical Approaches

Time-multiplexed operation at the 15 scene-per-second update rate and 30 scene-per-second refresh rate requires that during one frame time the system will process one problem for display at one of the two cockpit display stations. In the immediately following frame time, the second problem is processed and displayed at the second cockpit display station while the stored (and not updated) display of the first problem from the previous frame time is presented again. This process-and- record-followed-by-refresh display operation is accomplished for each problem on an alternating frame basis. This operation led logically to the system configuration and implementation shown in Figure 35. The investigations in Paragraph 5.2.5 address the consideration of the point of application of a record refresh function in the system, the options for a feasible implementation of this function, and the software and hardware area resulting from this choice and the other auxiliary requirements for this multi
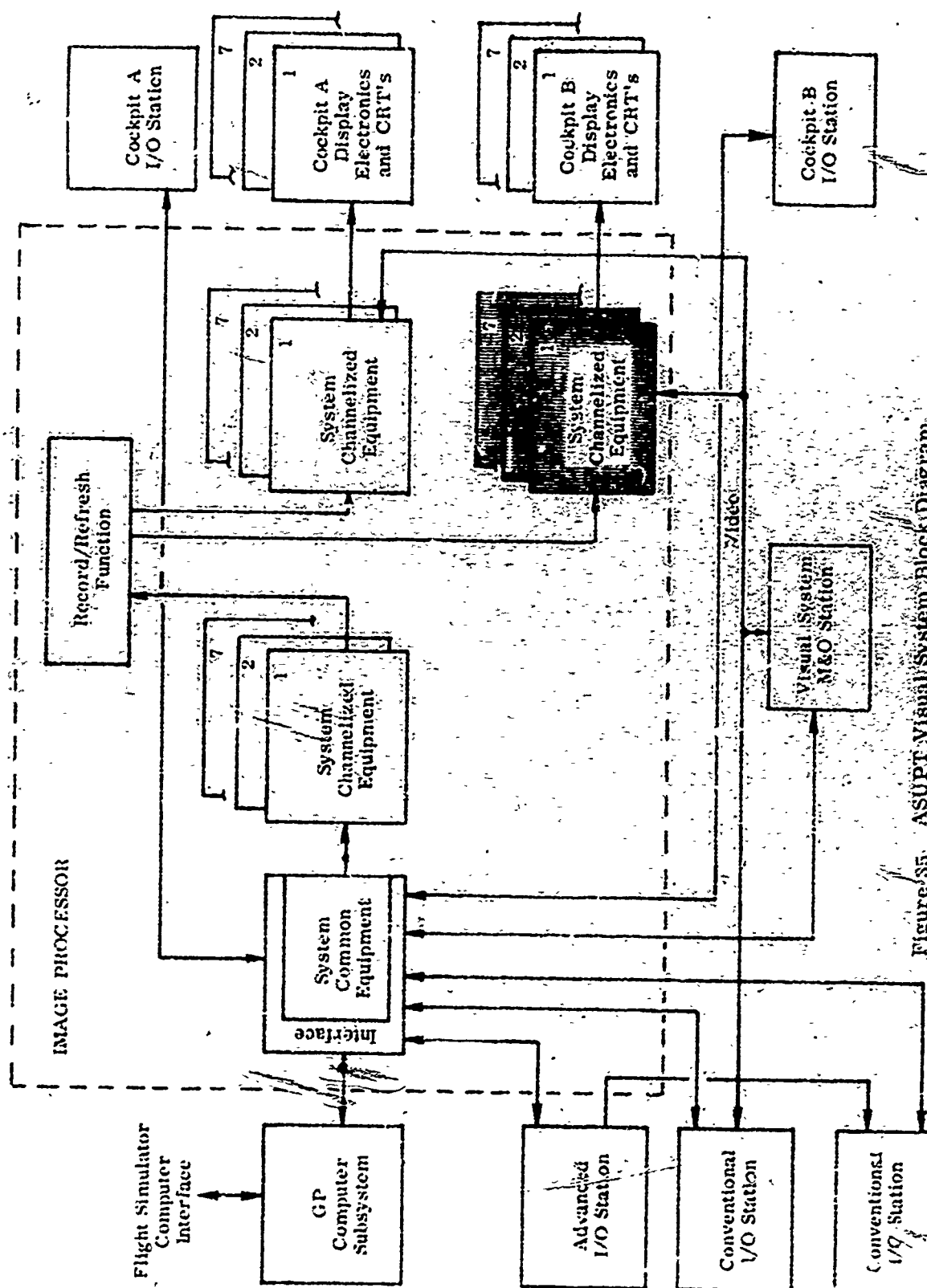
Figure 55. ASUPT Visual System Block Diagram Time-Multiplexed Mode Capability

Similarly, edge capacity-multiplexed operation requires the sharing of the total system capacity each frame time between two simulation problems to achieve 30 scene-per-second update and refresh rates in each display at the cockpit/display stations. These two problems will be processed sequentially through common equipment up to a point in the system where the display data must be diverted to drive the displays of each cockpit/display station. This operation led logically to the system configuration and implementation shown in Figure 36. The investigation in Paragraph 5.2.6 addresses the consideration of the optimum point in the system where this display problem divergence or multiplexing must occur and the resulting software and hardware impacts resulting from this choice and the other ancillary requirements of edge capacity-multiplexing.

The implementation of a dual-mode multiplexing capability as shown in Figure 37 follows logically from the integration and consolidation of the system configuration and implementation approaches for the individual modes. Paragraph 5.2.8 discusses briefly an alternative configuration of dual image processors which, given the necessary software modification, inherently provide for dual-mode operation. It is included for completeness in this report only as it obviously violates the requirement of obtaining a multiplexing capability with minimum system impact.

The investigations of Paragraphs 5.2.5 through 5.2.7 have been structured to discuss the impact of each mode of multiplexed operation upon the three major operational areas of the visual system which are general purpose computer subsystem operations, system interface operations, and image processor operations. The description of basic, non-multiplexed ASUPT visual system operations given in Paragraph 5.2.3 provides background for the consideration of the impacts discussed.

5.2.5 TIME-MULTIPLEXED OPERATIONAL MODE ASSESSMENT

5.2.5.1 Computer Operations

The major considerations and impacts on general-purpose computer processing operations imposed by this mode of time-multiplexed operation may be listed as follows:

a.   No impact on the basic environment data base and on the formatting of input data other than provision where appropriate for the addition of visual problem A/problem B identifier bits.

b.   Imposition of operational constraints on the motion rates of the aircraft and single moving model due to motion discontinuity effects.

c.   Minor modifications to the software executive program necessary to provide for management of two visual problems on an alternate frame basis and the handling of instructor/operator interrupts and requests for action pertaining to either one of two problems.

d.   No impact on the various on-line, functional software programs since they may be applied independently in alternate frame times under appropriate control and sequencing of the executive program.

e.   Addition of 8k core memory module to the computer subsystem to provide operating storage for the management and environment extraction data required in processing the second visual problem.
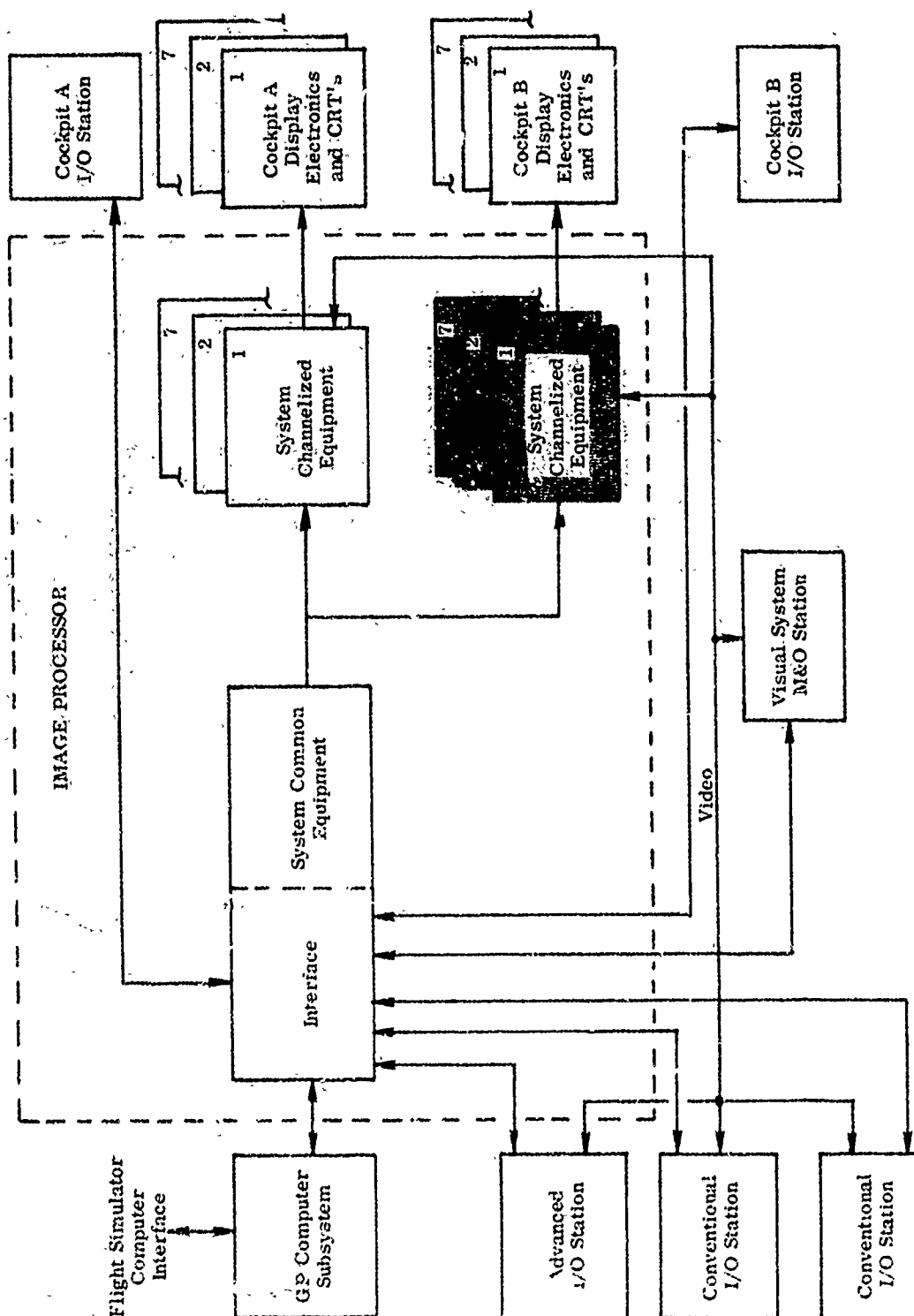
Figure 36. ASUPT Visual System—Edge Capacity—Multiplexed Mode Capability

96
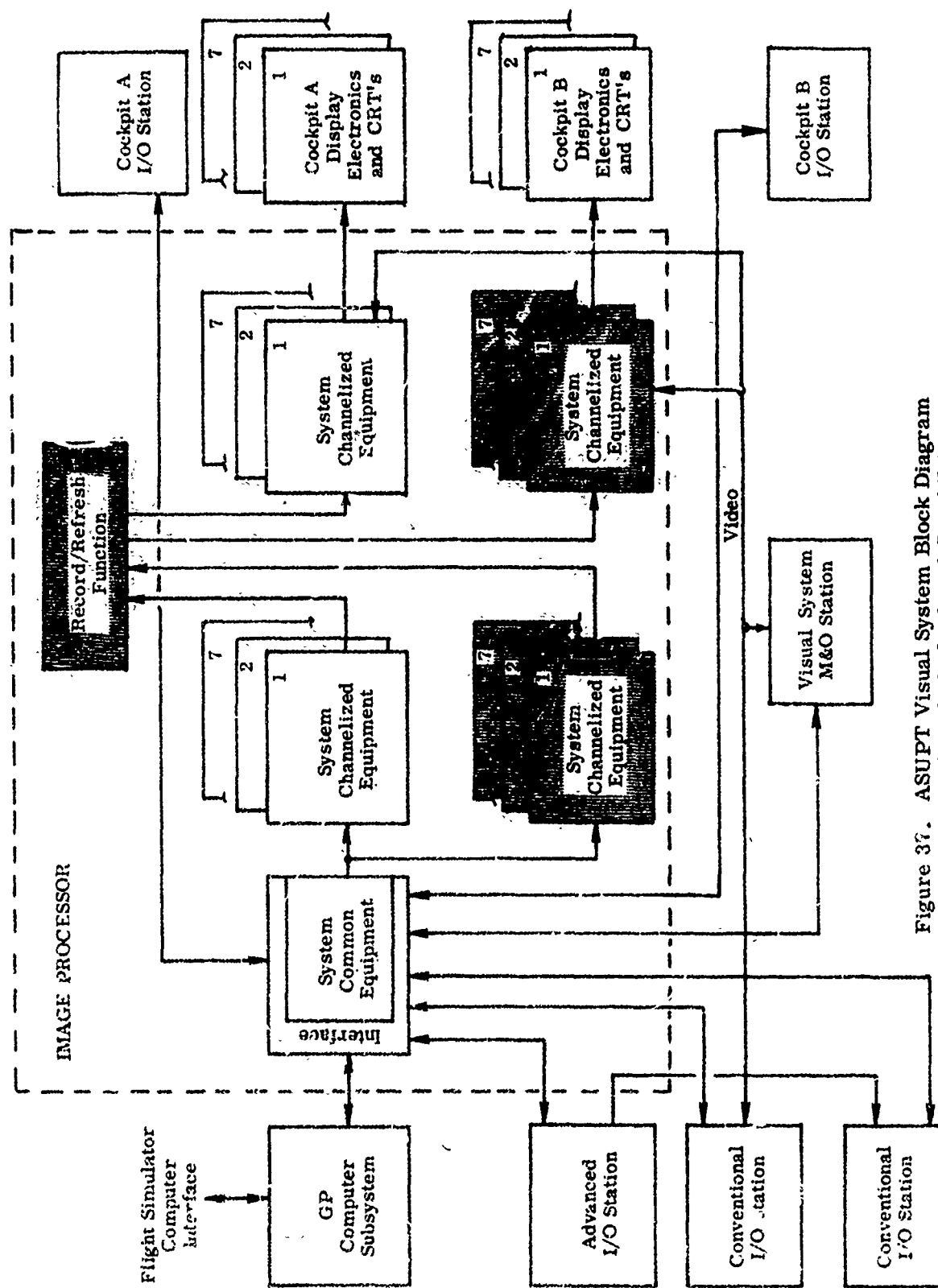
Figure 37. ASUPT Visual System Block Diagram
Dual Mode Multiplexed Capability

f. Minimal impact on the off-line diagnostic software package to provide checkout subroutines as appropriate for any additional functions added for time-multiplexed operation.

The basic preparation, formatting, and modifying of the environment and the assembly operations to make up an environment data base for a simulation problem are not impacted by time-multiplexed operation. Two visual simulation problems involving two aircraft operating from the same or different station-point locations within this common environment may be processed independently in alternate frame times under appropriate executive program control to achieve two separate station displays at a 15 scene-per-second update rate.

Rapid translation and attitude rates of the station point and/or any moving model in a problem may present undesirable motion discontinuities to the viewer. These subjective effects have been investigated and reported in Paragraph 5.3. If time-multiplexing is required, reduction of these effects to an acceptable level will require selection of specific operational problems to limit motion rates.

5.2.5.2 System Interface Operations

The impact of time-multiplexed operation on the implementation of and interface with the instructor/operator stations will involve a minimal expansion of discrete controls and indicators to cover multiplexed operation.

In this mode it is assumed that the advanced instructor/operator station would incorporate the following additional functions:

a. Equipment status and confidence indications expanded as appropriate to include the additional modes of operation.

b. Provision for the switch selection of multiplexed modes of operation (time multiplex and/or edge capacity multiplex) in addition to the non-multiplexed modes of individual and master-slave. Since the same function will be provided at the System Maintenance and Operations Station for independent operation, that station would provide the means of designating which station assumes control.

c. Program status and operating data indications pertaining to the concurrent operation of the second program.

d. Provision for a program A and program B selector switch to allow existing program entry switches such as "Program Freeze" and "Program Rerun," etc., to be activated for the training problem desired and to affect only the problem designated.

The CRT monitors provided at this station in the basic system will allow selection of any two channels of either cockpit display. In the time-multiplexed mode of operation, it may be a desirable option to add additional CRT monitors with similar display selection capability to allow viewing of a portion of both problems being run concurrently and this capability is assumed as an impact herein. Of course, this capability can be extended in each case to include more monitors and more display view channels; however, these configurations should be considered as operational display options judged against their value in the conduct of training (and/or diagnostic) operations and should not be assessed as an impact required by multiplexed operation.

Consistent with the monitoring and control capability to be provided at the conventional and cockpit instructor/operator stations, the control and indication functions associated with program status reporting and program entry control will be expanded at these stations in a proportionate manner to handle the second problem in multiplexed operation. The visual system Maintenance and Operations Station will include these additional second problem status and reporting data indications as provided at the advanced instructor/operator station. The provision of two additional display monitors is assumed.

5.2.5.3 Image Processor Operations

The major considerations and impacts on image processor operations imposed by time-multiplexed operation may be listed as follows:

a. The addition of 40,000 words of core memory to service the environment data base for the second problem.

The minor impact of the addition of several logic boards of digital circuitry for counting, control, and gating functions to handle the multiplexed switchover between problem data each frame time.

c. The major impact of the addition of the required record/refresh function.

d. The duplication of all channelized equipment after the point of application of the record/refresh function.

Since the memories containing operational data are not reloaded each frame time, the time-multiplexed mode of operation will require increased memory capacity to provide the additional data base capability to service a second simulation problem. No increase in memory is required to service the coordinate reference data since new data is transferred each frame time.

The common processing equipment must access different data base locations and stored or hardware constants for each problem. Several logic boards of digital circuitry are estimated to be required for functions of addressing, gating, limited semi-conductor storage, and control. Otherwise, the processing of environment data through the system common equipment is conducted on a continuous, serial "pipeline" basis and is completed each frame time for a display scene. These operations are performed in each frame time (albeit on different data in succeeding frames) in the same manner as for non-multiplexed operation; therefore, other than the minor addition of control functions referenced previously, no impact or hardware addition results in these specific computation and ordering operations.

The processed environment data that are output from the system common equipment are multiplexed into their associated channels of the system channelized equipment. Up to the point of application of the record/refresh function, all channelized operations are performed on each problem in alternate frames, and no hardware duplication is required. After the point of application of the record/refresh function, all channelized functions and equipment must be duplicated. During one frame time, this latter channelized equipment associated with one cockpit/display station will be processing on-line data (at the same time it is being recorded); the other station will be processing recorded data from the previous frame presented at that station. The details of the record/refresh function are discussed in Paragraph 5.2.5.4.

5.2.5.4   Record/Refresh Function

5.2.5.4.1   General

Basically, the overall problem of recording and refreshing in the ASUPT configuration requires the resolution of the following major points:

a. Selection of the optimum point in the system for recording (which inherently involves the solution to the problem of analog versus digital recording as well).

b. The basic timing considerations to consistently achieve accurate data recording and retrieval.

c. Selection of a device type (disc, drum, tape, etc.) which will most nearly fit the timing constraints, volume requirements (amount of data), and result in minimal cost impact to achieve the above.

Having considered such points, a recommended configuration will be briefly described as a summary to the discussion of this portion of the study.

5.2.5.4.2   Selection of System Recording Point

One of the major points which must first be decided in choosing the optimum point in the ASUPT system for recording is that of analog-versus-digital recording. Since there is only one point where analog (video) may be picked off in this system (just after the digital-to-analog converter), it must be decided whether or not this video signal can be recorded at all, even if in somewhat modified form. The bandwidth of the video signal which is to be recorded is related to the transition time selected to implement the change from one face to another. Optimum results are obtained when this is set at approximately one element-time (25 nanoseconds). This implies a video bandwidth of 16 MHz and, therefore, represents the required bandwidth of the recorder if analog recording is used. Since transitions in this video signal approach 16 MHz in frequency characteristics, it does not appear feasible to attempt to record this signal directly.

Two methods of splitting the signal into many elements and recording each element on separate tracks were investigated. One, involving the technique of breaking the basic video pass-band into multiple (lesser bandwidth) pass-bands through use of filters and mixers, was finally discarded primarily because of expected phase difficulties in recombining the various signals into one composite. It was found that techniques of this type had been employed in the past and had been successful only with great difficulty and then only with pass-bands below that required for the ASUPT system.

A second method was also investigated, that of demultiplexing the digital data stream just prior to the D/A's into multiple D/A's, each one representing only a portion of the data of the composite stream. Each of these would then be recorded on a separate track and then multiplexed on output back into a single video signal. This represents a much more direct method than the aforementioned technique, but was also discarded, principally because of the timing difficulties involved and in the fact that it would require switching analog signals at or near a 40 MHz rate, too fast to be considered feasible without a great deal of actual hardware testing. If it could be made to work, this technique has the advantage of requiring the least amount of hardware, both in terms of the recording device itself, as well as in the peripheral hardware required to drive the recorder.

Another type of storage mode which might be utilized for time multiplexing is the use of a scan converter tube. In this mode (for a given display) during one 1/30 second, the image generation system would simultaneously write the scene on the display CRT and on the scan converter tube. During the next 1/30 second, when the image generation system is performing this function for another channel, the scan converter tube would refresh the display CRT with the same scene just shown. This mode would result in cost considerations very similar to those associated with the video recording technique discussed earlier. The use of a single-ended scan converter tube would assure precise registration of successive CRT displays, thus avoiding spatial flicker.

The major unanswered question regarding this technique is quite a serious one. If there's any difference in CRT image brightness, contrast, or other characteristics on successive images, it will result in flicker effects at a 15-per-second rate—a frequency to which the eye is exceedingly sensitive. Even minor amounts of such effects are quite distracting and destructive of efforts to achieve subjective realism. The all electronic recording techniques discussed offer assurance this will not occur. There was no opportunity during the course of this study to perform experiments to determine the degree and subjective effects of this flicker. At this time, it can only be stated that this approach is a contender and may well warrant more detailed consideration of hardware aspects if it can be determined that the results of applying it would be satisfactory for ASUPT requirements.

The digital recording method to be considered is narrowed down to defining the optimum point in the system for this digital recording. Various factors enter into this decision. Among them are the following:

   a.   The volume of data to be recorded should be minimal.

   b.   The data rate should be low enough to preclude recording difficulties

   c.   The data rate should be continous—i.e., not dependent on decision logic which might create discontinuous "bursts" of data, as opposed to a smooth flow of data where each clock pulse produces the next contiguous data point.

   d.   The amount of logic to be duplicated should be minimal.

Because of (d) above, the search must begin as near the final output of the system as possible and move deeper into the system until, optimally, all four criteria are met.

Figure 38 shows a diagram of the channelized equipment from which the criteria previously set forth must be measured. A quick look at the digital data just prior to the D/A indicates that this point must be discarded, since it fails both (a) and (b), even though it passes the (c) test and especially (d), since only the D/A and video amplifiers would have to be reproduced. The volume of data is extremely high, since every data point must be recorded, without regard to whether or not there is "uniqueness" about these data points, plus the fact that the recording rate would be near 16 MHz, outside the range of any practical recording medium.

The actual point which has been selected for the ASUPT system, using the method outlined above, is that point just prior to the data assembler. The volume of data to be recorded is less than half that of the point just prior to the D/A. In addition, the recording rate is near 4 MHz, rather than 15 MHz, well within the range of existing devices. Also, the data rate is continous, with no data "bursts." Its only disadvantage
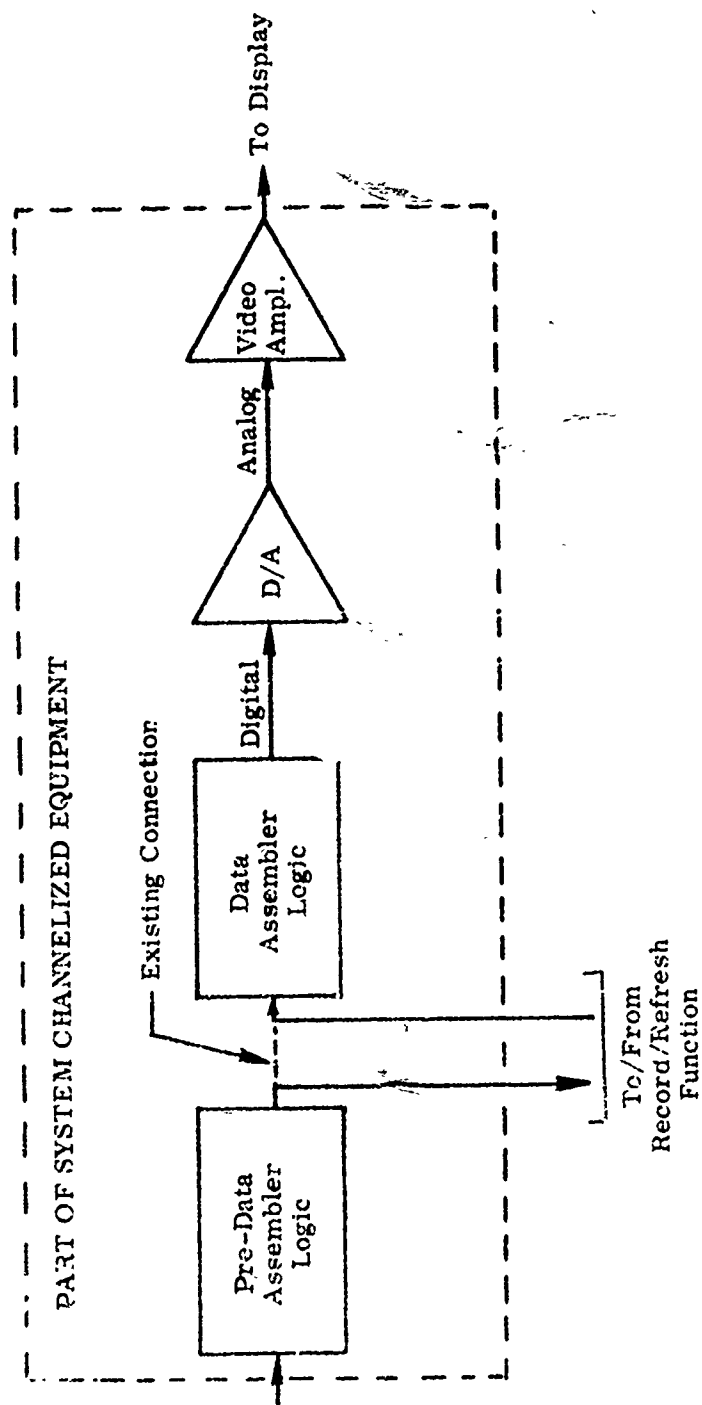
Figure 38. Selection of System Recording Point

is that the data assembler must be duplicated. To move further back in the system would require an even larger duplication, despite the fact that even lower data rates can be encountered (thought this generally results in a higher volume of data, also). Thus, the data point has been selected and is that point just prior to the data assembler.

5.2.5.4.3   Timing Considerations

In view of the fact that any record/refresh operation must of necessity be slaved to the existing system timing, it is necessary that any storage device selected be one which can be synchronized easily to the system clock. Since the data rate has already been defined to be near 4 MHz at this pick-off point, each data word is present for a maximum of about 250 nanoseconds; therefore, any error, in bit synchronizaton cannot exceed this time (indeed should ideally be much less) so as not to skip on repeat words. As a result, timing synchronization must be extremely accurate to prevent such errors from occurring.

5.2.5.4.4   Device Type Selection

In the selection of a device type for this task, all of the aforementioned points must be taken into consideration. Of the types to be discussed—tape, drum disc, or core—obviously only one can be optimum to meet all the requirements previously defined.

First, magnetic tape cannot be considered practical for numerous reasons. The application actually calls for a tape "loop" configuration, rather than reel-to-reel (since the device must be in continuous operation for a much longer period of time than a single reel could handle), and no existing device is so configured. Additionally, timing stability would be woefully lacking, such that the device could not be synchronized at all to the basic system timing clock. Long-term reliability would be another problem, with head wear being a significant factor over a long period of time, as well as requiring much routine preventive maintenance to keep it operating.

Magnetic core is just not cost-competitive with the other devices, even though it is the most easily "synchronized" of all the device types. Thus, it cannot be considered the answer.

This brings us down to drums and discs. Neither of these devices can be considered unless they offer "synchronizable" configurations since timing would be a major problem without this feature. Fortunately, both types do offer such options (even though the field is very narrow) such that the choice between them must be made by considering such factors as long-term reliability, degree of synchronization, and experience level of the manufacturer offering the device. In all three points, the disc comes out on top. Since a much larger mass is rotating in a drum configuration than a disc, mechanical failures such as excessive bearing wear are a more frequent problem in such devices. Thus, long-term reliability is generally less for a drum. Additionally, again because of the larger mass, synchronization is more of a problem. One drum vendor, for example, quotes a synchronization accuracy of ±100 nanoseconds, while a disc vendor quotes half that value, or ±50 nanoseconds. Thus, this particular drum may be only marginally accurate enough, where the disc is well within the accuracy constraints of the system. An lastly, this same disc vendor has been manufacturing synchronizable (dc servo) disc units for a number of years, whereas the drum vendor built his for a single special-purpose usage for one contract. Thus, the recommended device type is a disc unit with a dc servo drive mechanism which meets all the requirements of the ACUPT configuration.

There are devices coming into production now which could offer even better parameters than the dc servo disc. For example, there are such devices as the "magnetic domain" unit built by Digital Development Corporation, which is a completely solid-state device. While its clock rates are limited to the neighborhood of only 125 kHz, similar devices produced by other companies claim to have the capability of multi-megahertz shift rates and are projected to be price competitive with drum and disc storage devices. Devices of this type can be driven directly by the system clock and, therefore, would require no special synchronization techniques; however, they are still in the developmental stage and thus are high risk items. As a result, they are not recommended at this time for the ASUPT system, but might bear a closer look at a later date.

5.2.5.4.5 Recommended Approach

Figure 39 depicts the data flow using the dc servo disc to time-multiplex each frame to alternate channels. In this configuration, one disc surface (of two surfaces on a disc) is dedicated to one channel whose timing is such that while one frame of data is being displayed in real time on that channel's CRT (Channel 1 B in the diagram), it is also being written on the disc. At the end of that frame, the function switches shown are switches to the opposite position such that the previously recorded data are now displayed on Channel 1 B's CRT, while the new frame's real-time data is directed to the CRT for Channel 1 A (and is also recorded on Channel 1 A's dedicated disc). Each frame time—30 times a second—the switches are moved to the opposite position. As a result, each frame of data is displayed twice on a given channel's CRT, which constitutes a 30-per-second refresh rate and a 15-per-second frame update rate.

Since the eventual configuration for ASUPT involves seven channels, this would require seven discs (14 surfaces). One servo drive unit is required with each disc unit. These rack-mounted units may be consolidated into several equipment cabinets or mounted in the logic cabinets on a distributed basis with the system channelized logic. The final physical configuration would be that optimized configuration which considers the packaging design of the entire image processor subsystem.

5.2.5.5 Conclusions

The system configuration and implementation approach shown in Figure 35 represents a feasible, practical, and optimal approach to providing an ASUPT visual system with a time-multiplexed mode capability. The investigations indicate no critical or significant development problems in attaining this capability.

In the last analysis, the decision to add this capability would appear to be based primarily upon evaluating its cost impact against the increase offered in facility utilization (allowing concurrent and independent operation of both cockpit/display stations) and the increase or decrease in training problem effectiveness achieved. This latter consideration relates to the probable imposition of operational constraints on the motion rates of the aircraft and moving model in a training problem in order to avoid motion discontinuity effects. The seriousness and criticality of these effects is amenable only to subjective evaluation and decision by those who will prepare and conduct the training activities planned for this ASUPT facility.

104
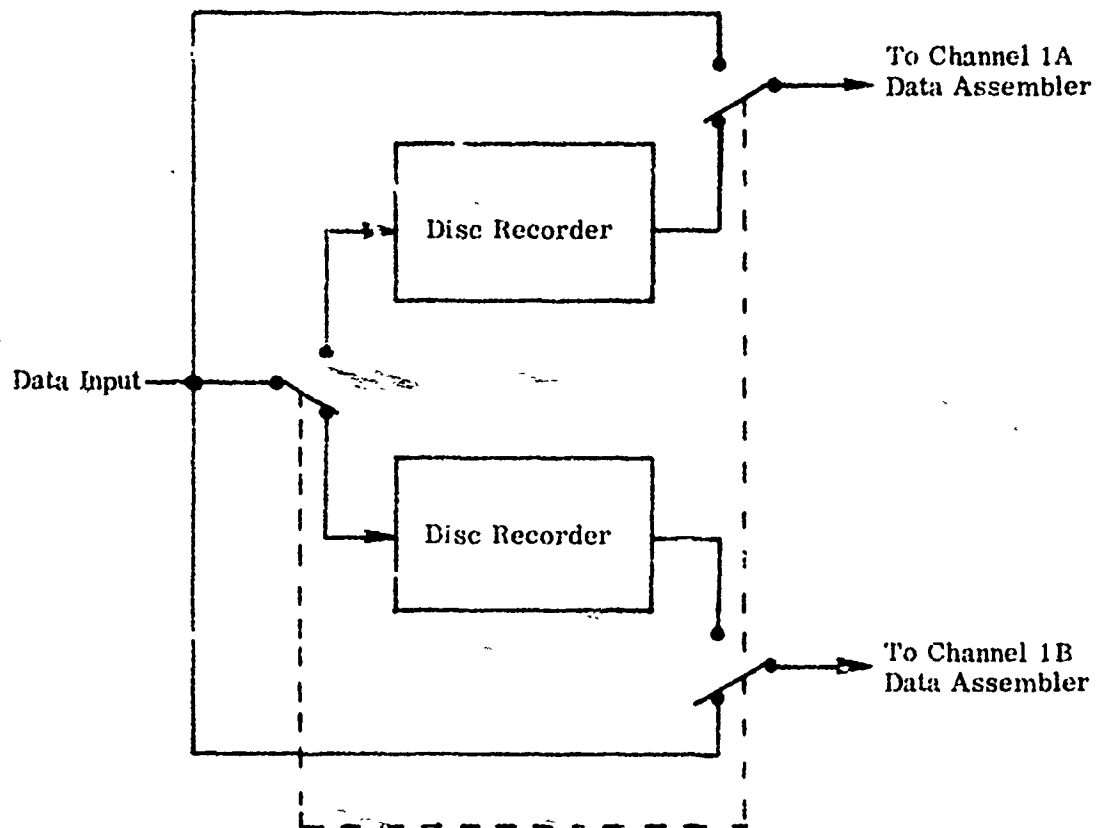
Figure 39. Functional Data Flow Diagram for Time-Multiplexed Operations

5.2.6   EDGE CAPACITY-MULTIPLEXED OPERATIONAL MODE ASSESSMENT

5.2.6.1   Computer Operations

The major considerations and impacts on general-purpose computer processing operations imposed edge capacity-multiplexed operation may be listed as follows:

   a.   An impact on the preparation of environment data bases and/or the environment extraction program.

   b.   Modifications to the software executive program necessary to provide for management of two proportioned environment visual problems in the same frame time and the handling of instructor/operator interrupts and requests for action pertaining to either one of the two problems.

   c.   No impact on the various on-line functional software programs (with the possible exception of the environment extraction program) since they may be applied independently in turn to each program under appropriate control and sequencing of the executive program.

   d.   Addition of 8k core memory module to the computer subsystem to provide operating storage for the management and environment extraction data required in processing the second problem.

   e.   Possible expansion of special-purpose computing functions required to support computer subsystem operations.

   f.   Minimal impact on the off-line diagnostic software package to provide checkout subroutines as appropriate for any additional functions added for edge capacity-multiplexed operation.

In the edge capacity-multiplexed mode of operation, two visual simulation problems must be processed in each frame time to achieve a 30 scene-per-second update rate for each problem. The maximum system's display processing capability must be shared or proportioned between the two problems.

As discussed in Paragraph 5.2.3.2, an environment data base whose environment content is a subset of the total environment is obtained from processing the total environment data base. The maximum environment content that can be processed is a function of specified system display processing capability; therefore, the maximum environment content capability that is available to service one problem must be proportioned to service each problem in this mode. From the processing of these two reduced environment data bases in the image processor, the seven-channel visual scenes for each problem and cockpit/display station are generated. The requirement exists during initialization and on-line operations to maintain these data bases within their proportioned limits so as not to exceed system display capability and cause unacceptable displays for either one or both problems.

Alternate approaches to assure proportioned operation of two problems in a satisfactory manner without system overload would be the following:

   a.   Utilizing initial judgment in the modeling of one common total environment data base (in which both aircraft would operate unrestrictedly) with reduced average and localized environment densities.

b. Build more extensive testing algorithms into the environment extraction program to minimize the possible adverse corrective action effects discussed previously.

c. Model two environments of proportioned average and local densities such that each problem is serviced by its own environment data base.

The first approach requires additional modeling or remodeling effort to generate a separate data base with reduced environment densities. The environment density would be governed by the smaller environment detail allocated in a problem pair. A potential disadvantage of this approach is the subsequent under-utilization of full system capability in the single problem mode. Separate data bases would need to be developed for each problem pair having different content proportionments.

The second approach adds additional modeling complexity to the single-problem data bases and to the operations performed by the environment extraction program and would be expected to represent a greater software impact.

The third approach requires modifying the model of the environment data base to provide acceptable subdata bases for each problem with reduced densities matching the scene content allocated to each problem. The data base storage capacity of the computer subsystem mass storage device would be shared between the two reduced density data bases. This approach is the most straightforward approach and would appear to offer the most effective utilization of total system edge capability as it is shared between the two problems. While all the approaches are feasible, the software impact is assessed upon this approach.

The libraries or catalogs of environment features prepared for non-multiplexed mode data base and the data base formatting and assembly programs may be used preparing proportioned data bases; therefore, excepting modifications to the environment extraction program (which may always be considered), the software impact in this area of two problem operation would be those efforts entailed in the preparation of additional proportioned, individual environment data bases.

If it is planned to develop one common environment data base which will service all variations of single training problems, then this effort represents additional unplanned software effort to generate the separate data bases by selective modification to the total environment data base. This software effort should not be viewed as a major impact area.

5.2.6.2 System Interface Operations

As discussed under Paragraph 5.2.5.2. the assessments made on the impact of time-multiplexed operation will apply identically for the edge capacity-multiplexed mode except for any control and status reporting on the record/refresh function equipment which is peculiar to time-multiplexed operation. The operation of the system in this mode will be controlled by the executive program and will be determined by parameter entries into the software programs, use of the appropriately modified functional programs where applicable, and the choice of the proportioned environment data bases to be used. Other than for a console mode selection switch, it is not anticipated that problem-allocation switches of any type will be used at the instructor/operator stations since these determinations are software-based.

107

5.2.6.3 Image Processor Operations

The major considerations and impacts on image processor operations imposed by edge capacity-multiplexed operation may be listed as follows:

    a.   The minor addition of several logic boards of digital circuitry to accomplish gating, counting, control, and semiconductor storage associated with handling the second problem in the system common equipment.

    b.   The major impact of duplication of all system channelized equipment.

Since the basis for this mode of operation is the sharing of the total system computational capacity between two problems, the environment that can be processed in this system common equipment must be shared similarly or otherwise the system would be overloaded; therefore, the non-multiplexed data-base storage will be shared. It is assumed that attention given to the formatting of data and their entries into this storage will allow no increase in memory storage requirements. The same considerations apply to the memory requirements for data needed to service special effects processing operations.

Coordinate reference data are entered each frame time corresponding to each new position and attitude of the vehicle and any moving model. These memory requirements are small. This memory might be time-shared with coordinate reference data for the second problem transferred from the computer subsystem later in each frame time when the second problem processing begins. Since the memory requirements are not large and in the interest of simplifying system timing, it is assumed that these memory requirements will be duplicated to allow simultaneous storage of coordinate reference data for both problems at the start of each frame.

As for time-multiplexed operation, the common processing equipment must access different data base locations and stored or hardware-wired constants for each problem in the frame time. In addition, the special effects processing operations will generate data tables that service the system channelized functions. The storage requirements for this data are small. Since the data to be stored would be reduced corresponding to the reduction in each problem's scene content, the same memory requirements could be shared for each problem's data; however, additional control logic of an insignificant amount would be expected to accommodate this operation.

Several logic boards of digital circuitry are estimated to be required to service collectively the functions of addressing, gating, limited semiconductor storage, and control.

Again, each problem's environment data is processed in turn through the system common equipment within the same frame time. The same basic operations are performed as for non-multiplexed operation and, except for the additional logic functions previously discussed, no impact or hardware addition results in these specific computation and ordering operations.

The channelized scene data must be separated and processed for each station. The practical meeting of these requirements results in the major hardware impact of complete duplication of system channelized equipment for this edge capacity-multiplexed mode of operation. Without duplication of the equipment, multiplexed operation would require unfeasible element data processing rates of 80 MHz (twice the 40 MHz required in non-multiplexed or time-multiplexed operation) and entire redesign of this portion of the visual system.

108

5.2.6.4 Conclusions

The system configuration and implementation approach shown in Figure 36 represents a feasible, practical approach to providing an ASUPT visual system with an edge capacity-multiplexed capability. The investigations reported on in this section indicate no critical or significant development problems in attaining this capability.

In the last analysis, the decision to add this capability would appear to be based primarily upon evaluating its cost impact against the increase offered in facility utilization (allowing concurrent and independent operation of both cockpit/display stations) and the increase in training problems effectiveness achieved.

The basic constraint in this multiplexed mode is that the total system environment display capacity must be proportioned between two problems to provide two displays of reduced environment content; however, motion rates are not restricted in this mode. This constraint may or may not be a serious training limitation. For example, in a 700/300-edge problem pair, the 700-edge environment may be adequate to conduct a training problem involving takeoffs and landings. The paired 300-edge problem then might be sufficient to conduct a training problem involving high altitude maneuvers and acrobatics where limited terrain detail will suffice.

The suitability of proportioned paired-problem, operation in this mode is heavily dependent upon subjective evaluation and decision by those who will prepare and conduct the training activities planned for this ASUPT facility.

5.2.7 DUAL MULTIPLEXED MODE IMPACT ASSESSMENT

5.2.7.1 Summary

Paragraphs 5.2.5 and 5.2.6 have discussed the functional and hardware impacts occurring from the addition of a time-multiplexed or an edge capacity-multiplexed mode of operation, respectively, to a basic non-multiplexed ASUPT visual system. This section considers the addition of both modes to the basic system.

The combined considerations and impacts on computer processing operations for the provisions of a dual mode capability may be listed from the previous sections as follows:

a. An impact on the preparation of environment data bases and/or the active environment extraction program (dictated by the edge capacity-multiplex mode).

b. Possible imposition of operational restraints on the motion rates of the aircraft and single moving model due to motion discontinuity effects (dictated by the time-multiplexed mode).

c. Modifications to the software executive program necessary to provide the management of two visual problems in either mode (software effort required would be expected to be somewhat less than the summation of the individual mode reprogramming efforts).

d. No impact on the various on-line functional software programs (with the possible exception of the environment extraction program) since they may be applied independently in turn to each problem under appropriate control and sequencing of the executive program.

e. Addition of 8k core memory module to the computer subsystem to service the additional operating storage requirements of either problem (no summation of memory requirements is involved).

f. Possible addition of special-purpose computing functions required to support computer subsystem operations (dictated by the edge capacity-multiplexed mode).

g. For either mode, minimal impact on the off-line diagnostic software package.

For system interface operations, the addition of any program operation indicator lights and selector switches will service both modes of operation. Except for the record/ refresh function, equipment status and confidence indications will service both modes. The impact will be essentially that of either mode alone.

In image processor operations, the duplicated functions and system-channelized equipment required for the edge capacity-multiplexed mode include those required in the time-multiplexed mode. The image processor memory requirements and the record/ refresh function will be required additionally to service the time-multiplexed mode.

For dual mode operation, the hardware impact is significantly less than that obtained by the summation of hardware requirements for each mode individually, but obviously greater than for either mode individually. The system availability considerations discussed in Paragraphs 5.2.5.4 and 5.2.5.5 apply herein to this dual-mode equipment configuration.

5.2.7.2 Conclusions

The system configuration and implementation approach shown in Figure 37 represents the logical integration and consolidation of the approaches proposed for the individual modes. To the extent that they are considered feasible, practical, and optimal, this dual mode capability is considered the same. Similarly, no critical or significant development problems are envisioned. The constraints and possible limitations discussed for these individual modes must be evaluated in total for this dual-mode capability.

In the last analysis after evaluation of the individual modes, the decision to add this capability would appear to be based primarily upon evaluating its additional cost over and above those of each individual mode against the gain in benefits of having both modes of multiplexed operation.

5.2.8 DUAL IMAGE PROCESSOR CONSIDERATION

Obviously, the extreme and limiting case for implementing either multiplexed mode capability or the combination of both modes is that of duplication of the computer subsystem and the image processor. This approach represents and provides the full capability of two systems. Approaching this extreme is the duplication of the entire image processor—common and channelized equipment—as shown in Figure 40. This configuration will provide both modes of multiplexed capability assuming implementation of the associated computer subsystem modifications. The multiplexing function here involves the sharing of the common computer subsystem.

In time-multiplexed operation, the digital disc unit record/refresh function would be replaced by the processing of each problem's environment data base (before updating) a second time to generate the refreshed display. In edge capacity-multiplexed operation, the requirement for proportioned environment problem pairs becomes dictated
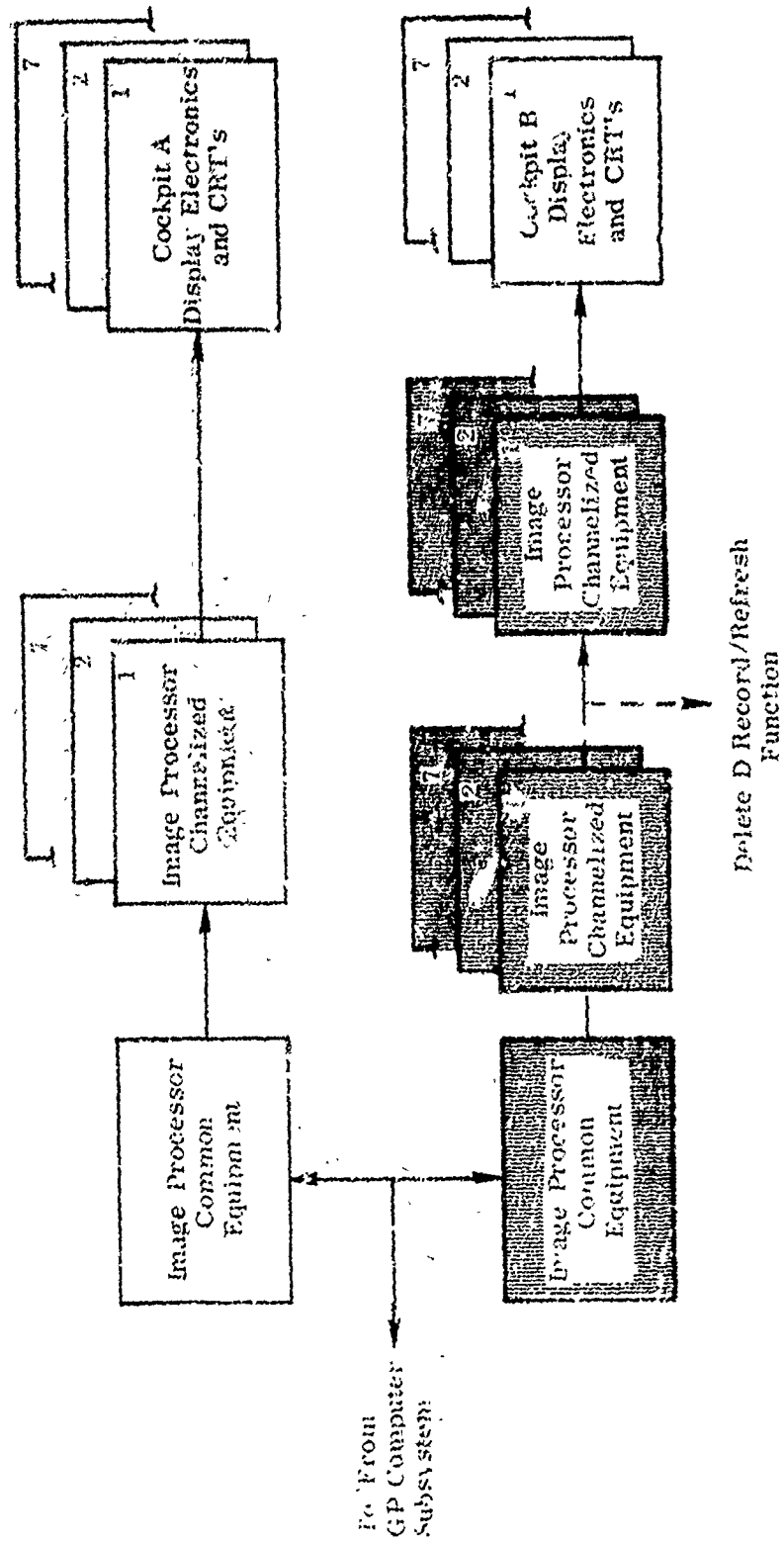
110

Figure 40. Possible Dual Image Processor Configuration for Multiplexed Mode Operation

111

by the computer subsystem's frame processing time capability since full image processor capability is provided in each display path.

The additional racks of image processor-common logic required in this approach as compared to the corresponding dual-mode approach of Paragraph 5.2.7 would cost more than the eliminated record/refresh function, provide less system availability for these modes of operation (because of the large number of additional components and connections), and require more air conditioning and ac power. These differences would be further emphasized if this approach is compared to either multiplexed mode approach of Paragraphs 5.2.5 or 5.2.6 alone; however, with switching provided to interconnect the image processors' outputs to either cockpit/display station, this approach would provide greater system availability in non-multiplexed, single-problem operation because of the redundant image processor paths.

The approaches investigated in Paragraphs 5.2.5 and 5.2.6 (or their combination) represent two alternate and feasible approaches to attain a dual ASUPT display capability, each with certain constraints or limitations. The dual image processor configuration discussed herein represents a third alternative with the same limitations and with additional disadvantages. This possible approach is not considered cost effective and is referenced here primarily for completeness in this display multiplexing study report.

5.3 MOTION DISCONTINUITY EFFECTS INVESTIGATION

5.3.1 INTRODUCTION

This section contains the results of the subjective evaluation of motion discontinuity effects, including tradeoffs and conclusions, to establish the feasibility of display multiplexing. The section also documents the analysis and results of the motion discontinuity effects study to indicate the practicality of display multiplexing as a function of the intended training missions.

The time-multiplexing mode would provide for two cockpit displays being driven by a single image generation system with each cockpit display system operating at full edge capacity. This would be accomplished by computing scenes for the two display systems on alternate cycles, storing the completed scenes, and displaying each scene twice in succession to maintain a 30-frame-per-second scene refresh rate and prevent objectionable flicker. The result of this multiplexing technique would be a reduction of the motion update rate from 30 times per second to 15 times per second.

When the motion update rate is reduced to achieve multiplexed operation, the motion discontinuity effects become more pronounced. Although image motion between updates can be easily computed, as a function of update rate and aircraft rates, the visual effect of given amounts of movement can only be evaluated by visual means. That is, a given movement between updates cannot be catalogued as acceptable or unacceptable based solely on the amount of movement nor the rate of movement. A certain amount of discontinuity may be acceptable for certain training objectives and/ or operational modes, and completely unacceptable for other objectives and/or modes.

The motion discontinuity effects investigation was concerned solely with the subjective evaluation of the effects of reducing the motion update rate from 30 times per second to 15 times per second to achieve multiplexed operation.

5.3.2 OBJECTIVES

The objectives of the motion discontinuity effects investigation were to determine and demonstrate the conditions and operational modes under which display multiplexing, via reduced motion update rates, can be used without adversely affecting associated training missions due to motion breakup effects attributable to the slower update rates.

5.3.3 CONCLUSIONS AND RECOMMENDATIONS

It is in the acrobatic maneuvers that motion discontinuity effects are most evident. The maneuvering rates which produce these objectionable effects during acrobatics occasionally occur during more routine maneuvers. That is, high roll and yaw rates can be experienced during landing approaches and turns. High pitch rates can be experienced during altitude changes. These high rates are somewhat disruptive and visually distracting but are relatively short duration. On this basis, it is concluded that the display multiplexing with 15 Hertz update rate can be used in such maneuvers as normal take-offs and landings, taxiing, and high altitude level flight. This conclusion is supported by the considerable experience in flying the NASA II visual system in Houston, which used 20 Hertz update and refresh rates, and in flying the more limited edge capacity visual systems of the General Electric Electronics Laboratory in Syracuse and in Daytona with the 15 Hertz update rates.

In medium to low altitude level flight, use of this multiplexing mode is considered marginal, and during acrobatic maneuvers, this multiplexing mode should not be considered unless the rates are below the 20 degree/second range. Acrobatic maneuvers performed at the higher angular rates will be accompanied by some distracting effects. The severity of these effects will depend on both the rates encountered and the duration of the rates. It is anticipated that the degree of distraction will not be significant except near the operational limits of the aircraft. Such rates would not be expected to be reached often, nor would they be maintained for long except possibly in test pilot training.

It is recommended that display multiplexing by reduced motion update rates not be considered as an option to the ASUPT primary visual system unless a significant portion of the system operating time is expected to be dedicated to training research in those modes where the distracting effects are minimal.

5.3.4 APPROACH

Due to the subjective nature of this evaluation, video tapes were made from a real time computed image generation facility with sequences matched to operational training modes and motion update rates. The demonstration video tape sequences were planned to depict the transitional region between acceptable and unacceptable effects in each operational mode when using the slower update rates.

5.3.5 IMPLEMENTATION

The sequences to be video-taped were chosen by careful study of aircraft operational modes and aircraft performance capabilities. The operational modes represented on video tape, in the order of occurrence, are: taxi, approach and landing, high altitude level flight, medium altitude level flight, low altitude level flight, high altitude acrobatics, and low altitude acrobatics.

All sequences were taped in black and white from a real time image generation system with horizontal raster scan, two to one interlace, and 30 Hertz picture refresh rate. Field-of-view is 60 degrees horizontal by 45 degrees vertical. Resolution is approximately 480 lines vertical by 800 elements per line, horizontal. The environment data

113

base used for all sequences consisted of 24 edges configured to represent an unmarked runway, ground plane texturing, and a stationary target aircraft. The effect of more than 24 edges is achieved by unique edge sharing features of the laboratory system used for the taping session.

All operational modes are first shown with the normal 30 Hertz motion update rate. Each sequence is then exactly duplicated with a 15 Hertz motion update rate. In both cases, a 30 Hertz picture refresh rate is used.

Some noise and occasional picture dropouts will be observed in the video tape. These effects are due to tape or recording imperfections only. The effects are independent of motion update rate and are not present in live demonstrations of real-time computed images.

5.3.6 EVALUATION

5.3.6.1 General

It appears that the video tape sequences were well chosen and clearly illustrate the effects of motion update rate throughout the range of aircraft operational modes and dynamic rates. A run-by-run evaluation of the sequence listed in Table IV follows.

5.3.6.2 Taxi

For the taxi sequence with a 40-knot speed, no discontinuity effects are observed with 30 Hertz or 15 Hertz motion update rates. It would appear that this mode of operation will be unaffected by 15 Hertz motion update rates.

5.3.6.3 Normal Approach and Landing

For the normal approach and landing as described in footnote 2 of Table IV, discontinuity effects are minimal and are not considered distracting for either motion update rate. The only noticeable discontinuity occurs just prior to the time each visible edge passes off the bottom of the CRT face. This coincides with the highest relative motion rate of an edge across the CRT. It does not appear highly distracting due to the fact that it is near the edge of the CRT face and has very short duration. It would appear that this mode of operation will not be significantly affected by 15 Hertz motion update rates

5.3.6.4 Low Altitude Level Flight

Low altitude level flight simulations were made at 300 feet altitude, with both 200 and 475 knot speeds. Sight line was both ahead and 90 degrees left. The motion discontinuity effects become distracting for low level flight at the higher speed with the 15 Hertz update rate. Depending on the speed, environment detail, grey-scale changes at each edge, and training objectives, the effects may be considered severe enough to impair training effectiveness.

5.3.6.5 High Altitude Level Flight

Even the sensation of motion is difficult to perceive at the 30,000-foot altitude level. No motion discontinuity effects are evident.

114

Table IV

FLIGHT PATH DESCRIPTIONS

	Description	Run	Altitude (Ft)	Sight Line	Speed (Kts)	Comments
1.	Taxi	1.1	8	Ahead	40	(1)
2.	Approach and Landing	2.1	Var	Ahead	Var	(2)
		2.2	Var	90° Left	Var	(2)
3.	Low Altitude Level Flight	3.1	300	Ahead	475	
		3.2	300	Ahead	200	
		3.3	300	90° Left	475	
		3.4	300	90° Left	200	
4.	High Altitude Level Flight	4.1	20,000	Ahead	475	
		4.2	20,000	Ahead	200	
		4.3	20,000	90° Left	475	
		4.4	20,000	90° Left	200	
5.	Medium Altitude Level Flight	5.1	4,000	Ahead	475	
		5.2	4,000	Ahead	200	
		5.3	4,000	90° Left	475	
		5.4	4,000	90° Left	200	
6.	High Altitude Acrobatics	6.1	10,000	Ahead	200	5°/Sec Roll
		6.2	10,000	Ahead	200	130°/Sec Roll
		6.3	10,000	Ahead	200	20°-40°/sec Roll (3)
		6.4	10,000	Ahead	200	5°/Sec Yaw
		6.5	10,000	Ahead	200	20°-40°/Sec Yaw (3)
		6.6	10,000	Ahead	200	5°/Sec Pitch
		6.7	10,000	Ahead	200	20°-60°/Sec Pitch (4)
7.	Low Altitude Acrobatics	7.1	300	Ahead	200	5°/Sec Roll
		7.2	300	Ahead	200	130°/Sec Roll
		7.3	300	Ahead	200	20°-40°/Sec Roll (3)
		7.4	300	Ahead	200	5°/Sec Yaw
		7.5	300	Ahead	200	20°-40°/Sec Yaw (3)
		7.6	300	Ahead	200	5°/Sec Pitch
		7.7	300	Ahead	200	20°-60°/Sec Pitch (4)

(1) Each run to be of 15 seconds duration unless otherwise specified.

(2) Approach—landing speeds, altitude as follows:
    Approach —approximately 300 knots at 100 feet altitude
    Downwind—approximately 120 knots
    Final turn—approximately 110 knots
    Final approach—approximately 100 knots to flare
    Roll out —approximately 80 knots
    Time duration —approximately 1.25 minutes

(3) Angular roll and yaw rates varied from 20° to 40°/sec in 5°/sec increments. Each rate recorded for 5 second period; i.e., run duration of 25 sec.

(4) Angular pitch rate varied from 20° to 60°/sec in 5°/sec increments. Each rate recorded for a 5 second period; i.e., run duration of 45 sec.

5.3.6.6 Medium Altitude Level Flight

At the 4,000-foot altitude level, some motion discontinuity effects are detectable. Again, it is near the bottom of the CRT for a short time just prior to the time when each edge passes from the CRT face. The level of distraction is considered minimal.

5.3.6.7 High Altitude Acrobatics

In the acrobatic maneuvers performed at 10,000-foot altitude and 200-knot speed, all sensation of translational movement is lost. Only the effects of the individual roll, pitch, and yaw maneuvers are evident.

5.3.6.7.1 High Altitude Roll

At the 5 degree/second roll rate, no discontinuity effects are observed. At the 130 degree/second roll rate, motion discontinuity is obvious at both the 15 Hertz and 30 Hertz update rate. Even though the effects are obvious, most observers do not classify the effects as objectionable nor distracting. Perhaps this is due to the fact that little information content is expected at such rates. The normal blurring effect experienced at such rates does not occur in the computed images, but it appears to make little difference how the picture information is lost. The sensation of high roll rates and low information content is preserved, and this appears to be of primary importance rather than the smooth continuity and subsequent blurring effect.

As roll rate is increased from 20 degrees/second to 40 degrees/second in 5-degree increments, several effects appear which may not have been previously noticed. If one concentrates on the center of the picture, little distraction is felt. Near the edges of the picture the distraction is much higher. The distraction and discontinuity at edges separating two low contrast regions are noticeably less than at edges separating two high contrast regions.

Another interesting point is that one might feel that the discontinuity effects of a 40 degree/second roll rate with 30 Hertz update and a 20 degree/second roll rate with 15 Hertz update would be the same. It appears, however, that additional effects are introduced in the case of the 15 Hertz update by showing each picture twice in succession. The effects appear as a different "flicker rate" in the region around each edge showing motion discontinuity.

The motion discontinuity effects of roll rates in the 20 to 40 degree/second range are noticeable even with a 30 Hertz update rate. The effects are not highly distracting, however. With a 15 Hertz update the effects are much more pronounced and considered marginally objectionable by most observers.

5.3.6.7.2 High Altitude Yaw

The 5 degree/second yaw rates cause no motion discontinuity at either motion update rate. In the 20 to 40 degree/second range, however, the effects become pronounced and distracting. In the case of a 30 Hertz update rate the distraction level occurs near the 30 degrees/second rate while even 20 degrees/second causes distracting effects with the 15 Hertz update rate. Again, the distracting effects are much less at edges separating low contrast regions than at edges separating high contrast regions.

5.3.6.7.3 High Altitude Pitch

The 5 degree/second pitch rates cause no motion discontinuity at either motion update rate. When pitch rate is varied from 20 to 60 degrees/second, the effects are similar

116

to the same condition in yaw. As would be expected, however, the effects of a given pitch rate are more pronounced than the effects of the same yaw rate. This is due to the 45 degree vertical field-of-view as opposed to the 60 degree horizontal field-of-view. At 30 degrees/second yaw, a one degree movement across the CRT occurs in 1/30 second. This is 1/60 of the CRT face. The same one degree movement occurs in 1/30 second for a 30 degree/second pitch rate, but the movement is 1/45 of the CRT face. The larger apparent movement also appears more distracting.

Accordingly, pitch rate appears to cause more distracting effects than comparable yaw rates. Extending the pitch rate to 60 degrees/second makes pitch rate compare even more unfavorably with yaw rate because the maximum yaw rate was 40 degrees/second. These limits were used because of the aircraft operational limits expected in real life.

Even with the 30 Hertz update rate, the motion discontinuity effects become distracting. In all cases, however, the 15 Hertz update rate is worse by more than the expected factor of 2 as explained earlier.

5.3.6.8 Low Altitude Acrobatics

Again 5 degrees/second roll rates caused no motion discontinuity at either update rate. For all other rates, effects very similar to the high altitude cases were observed. At the low altitude, the simultaneous effect of translational motion and angular rates was evident. This caused certain edges to have higher apparent motion across the CRT and was correspondingly more distracting.

It should be pointed out, however, that with 15 Hertz motion update for both high and low altitude pitch maneuvers, the effects were severe enough to almost cause nausea. The difference in high and low altitude effects is, therefore, rather insignificant.

Another significant point of distraction encountered in several of the acrobatic maneuvers is the multiple image appearance of small targets. This effect is consistent with other observed effects and manifests itself differently only when successive target positions on the CRT are non-overlapping.

(Reverse Side is Blank)   117

SECTION VI

EDGE SMOOTHING

6.1 INTRODUCTION

The major goal of the edge smoothing investigation was to obtain information on the degree of improvement in discontinuities in edges intersecting the raster lines at angles other than 0 to 90 degrees provided by application of various techniques. The following techniques were evaluated:

    a. Transition Time Control.
    b. Element Size Change.
    c. Contrast Change.
    d. Edge/Scan-line Orientation.
    e. Scan-line Width.

Major emphasis in the investigation consisted of evaluating the edge discontinuities in dynamic scenes and of producing 16mm film sequences for subjective evaluation of the various techniques. It is known from prior viewing of computer-generated image sequences that it is only under dynamic conditions that some of the effects become obvious; thus moving sequences are essential for evaluation. In addition, still photographs are provided for more convenient evaluation.

Another factor which was considered in setting up sequences for evaluation is element size. The smaller the element size and raster line spacing the less noticeable is the step effect. It is also true that no matter how small the element size, close inspection of the picture will reveal the original effect. Thus, the sequences were planned, to the maximum extent possible, to illustrate the results of each technique by a comparison of an appropriate scene with and without the technique being applied. Also, to allow at least some evaluation of the synergistic effects of a number of techniques applied at once, sequences were taken of a "typical" environment, containing fields, mountains, a runway, buildings, etc. Various combinations of techniques were applied to this scene.

Each technique of effect investigated will be discussed generally, followed by a description of the approach used for simulation and, finally, by a discussion of the results.

6.2 SUMMARY

The study effort achieved the goal of producing scenes, both still and moving, which can be used for comparative evaluation of the subjective effects of various factors affecting the display. Evaluation of these scenes shows strikingly the highly non-linear nature of subjective effects which had previously been known to exist in the case of flicker and of update-rate (or spatial-flicker) effects. For example, reducing the display element dimension by a factor of two causes a reduction in the effect of edge steps by a far greater factor.

In addition to the improvement gained by reduction of display-element size, other techniques help greatly. The transition time during which a scan-line changes from one shade to another can be controlled to approximate that provided when an actual television camera produces video from a scene. This improves results, compared with

119

more abrupt changes. The noticeability of the steps is a strong function of the bright-ness contrast across the edge—reducing the contrast helps greatly. The orientation between an edge and the raster scan lines is critical. At angles near 45 degrees, the effect disappears almost completely. This can be used to advantage in planning the system and in modeling.

The most significant result from the study is the very strong indication that when all the techniques are simultaneously applied and adjusted to optimum, the residual step effect can be reduced to negligible significance.

6.3 TRANSITION TIME CONTROL

6.3.1 GENERAL

For each raster scan line, the mathematical computations determine the specific scan element numbers at which new faces become present on the scan line. There will, in general, be one shade to the left of each such element and a different shade starting at the element. This is the feature of the Computed Image Generation (CIG) system which produces the step effect. This is shown on Figure 41, where the actual edge image is shown dashed. Five scan lines are shown, and transitions occur at elements 5, 11, 16, and 22. The stepped edge is clearly seen. It is more apparent when distances between steps are larger. When the edge moves slowly in a vertical direction, the changing transition element numbers impart an apparent horizontal motion on the edge. For this reason, an almost horizontal edge moving vertically, separating a black region from a white region, was chosen as a starting point to emphasize the effect to give more sensitive indications of the changes achieved by different techniques.

A helpful technique is to control the transition time between black and white, rather than to produce the abrupt transition shown. At first, this might appear to be a case of "blur the picture to hide the faults." That this is not the case is best seen by con-sidering why a similar effect does not occur in normal television viewing.

Figure 42 shows, at the top, scan line 3 from Figure 41, with the edge under discus-sion crossing it. Consider this now to be the image on the television camera. Eight successive positions of the scanning electron beam are shown. This beam is deliber-ately adjusted to have a spot size corresponding to the scan line width, as shown. In the lower part of Figure 42 is shown the voltage out of the camera with "black" and "white" levels identified. As the beam traverses the portion of the scan line contain-ing the edge, the output gradually changes from "black" to "white" with a transition time approximately equal to the slope of the image of the edge, expressed in scan ele-ments per scan line. The result is a stepless, sharp-appearing edge. There is, thus, sound theoretical justification for applying transition time control to moderate the step effect.

6.3.2 SIMULATION

An almost-horizontal edge, such as discussed in the previous paragraph, was pro-duced on a static scene generator. By programming a vertical movement between suc-cessive scenes and by photographing the scenes with a movie camera, a vertically moving edge was shown. It is first shown with no smoothi. Transition time is then set equal to slope to verify the analysis that this essentially eliminates the step effect for such an edge. The same scene is then shown with one-element smoothing to show that improvement results, but not elimination.
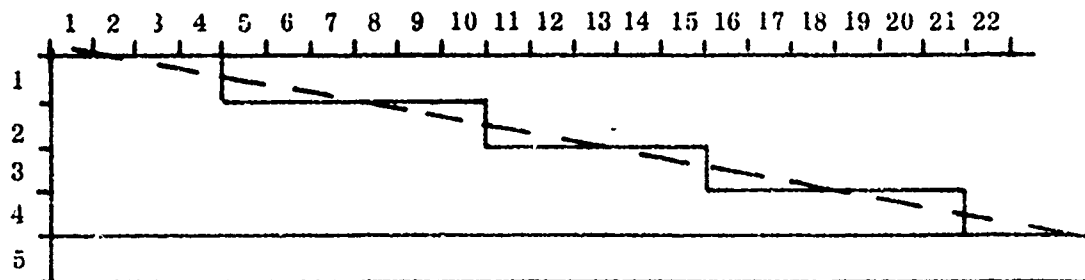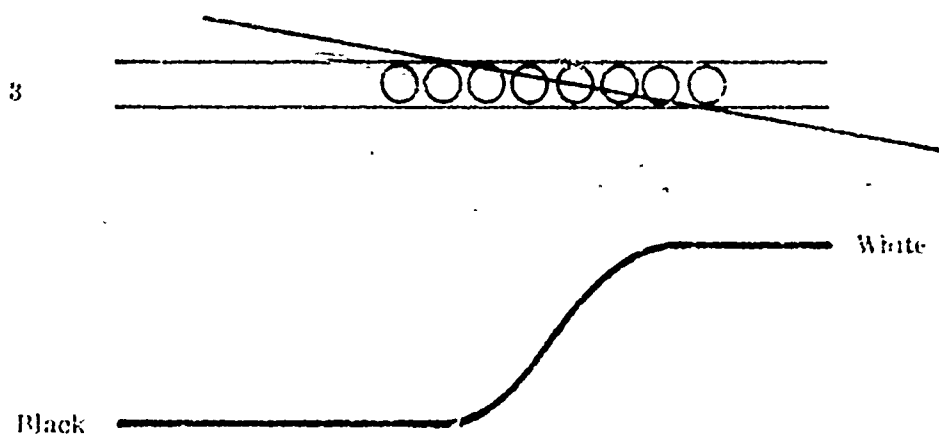
120

Figure 41.   Edge Step Effect

Figure 42.   Transition Time Produced by TV Camera

Next a near-vertical line is shown moving horizontally. It is shown with one-element smoothing. This setting, which significantly improves all except near-vertical edges, helps slightly, without degrading the edge as greater transition times do.

6.3.3 RESULTS

The results verify the previous analysis. The results also show that this technique cannot eliminate the step effect for near-vertical edges. A setting of one element time for transition time, which can be interpreted as providing signal frequency content consistent with sampling rate, results in improvement of both situations to the point where it can be considered for inclusion with other techniques for improving the picture quality.

6.4 ELEMENT SIZE CHANGE

6.4.1. GENERAL

The computed and displayed elements are quantized by scan line in one direction and by element number in the other. If the size of the quantized element is reduced, by a factor of two for example, the size of the steps is halved, the number of steps is doubled, and the spacing of the steps along the edge is halved. This is shown in Figure 43 for the same edge considered earlier. The improvement is obvious. This is the type of improvement which would result, other things being equal, in changing from a 500-line to a 1000-line system.

6.4.2 SIMULATION

The effect of element size reduction was simulated as follows. For each combination of edge and transition time, the sequence is first shown on the film as a 500-line display. A mask was then placed in front of the CRT so only half of the lines are seen— the middle 250. The camera then zooms in on the middle 250 lines until they fill the screen. This display (the middle 250 of a 500-line display) is compared with the film sequence immediately following, which is a simulation of the middle 500 lines of a 1000-line display. The simulation of the middle 500 lines of the 1000 line display was accomplished by adjusting the camera location and lens to produce the same field of view and apparent line spacing as would be seen viewing the middle 500 lines of an actual 1000 line display. The comparison with the 500 line display is shown to clearly demonstrate the results before and after the element size reduction. Viewing of the results indicates it achieved the goal of providing a subjectively valid simulation of the difference.

6.4.3 RESULTS

The results due to element size reduction was one of the more noticeable improvements. The non-linear nature of subjective effects (already noted in earlier investigations of flicker effect versus flicker rate and of "jumping-effect" versus update rate) seems also to apply here, making the effective improvement considerably more than a factor of two.

The sequences taken allow evaluation of the combination of transition time and element size reduction which show a very remarkable effect together.

122

6.5 CONTRAST CHANGE

6.5.1 GENERAL

Reducing the contrast between the two faces separated by an edge greatly reduces the effect of the edge discontinuities. Experimentation with dynamic scenes shows that significant improvements can be made by careful selection of shades for the faces while still having fully effective visual cues.

6.5.2 SIMULATION

In the majority of scenes which were planned for most sensitive evaluation of the effect of other techniques, the maximum possible contrast was used. One film sequence was designed for most sensitive evaluation of contrast differences using the near-horizontal edge with 250 scan lines filling the frame. In addition to the normal high-contrast shot, this scene was taken with low contrast, both without smoothing, and with one-element transition time. Additionally, in the airport scene, there is a variety of contrasts involved.

6.5.3 RESULTS

Moderate reductions in contrast significantly improve the results.

6.6 EDGE/SCAN-LINE ORIENTATION

6.6.1 GENERAL

The aforementioned sequences have had the edge oriented to give worst possible results in regard to step effect—both to provide sensitive evaluation of the measures taken and because, in use, such orientations will be among those which occur. The degree to which orientation affects the results is of importance so that if there is a particular situation in which the effect would be most objectionable, system orientation can be selected to minimize it under these conditions. An example might be where the horizon is near-horizontal and the steps could be used as non-real cues for attitude maintenance.

When the angle between the edge and the scan lines is 45 degrees, the step effect is minimum. In fact, a 45-degree orientation along with one-element-time transition causes the steps to completely disappear. For the example above, therefore, best results would be obtained by having the raster scan lines 45 degrees with respect to the horizontal.

6.6.2 SIMULATION

The effect of the edge-scan-line orientation is simulated in two scenes. A horizon is slowly rocked around horizontal with horizontal raster lines. This is then repeated with 45-degree raster lines. In both cases high contrast is used for sensitive evaluation of this effect. One-element transition time is used since it is this in combination with the orientation which is to be evaluated.

6.6.3 RESULTS

The slow rotation of the edge produces a continually changing slope and hence a step effect with horizontal raster scan lines. With the 45-degree scan lines, the step effect on the horizon is completely absent. It is important that the modeller be aware

of the significance of this, as well as other effects. If, for example, landing exercises are planned and if the system has horizontal scanning, then a few distant mountains beyond the end of the runway will eliminate the undes... ...ole cues. A better solution would be to orient the raster lines at 45 degrees.

6.7 SCAN-LINE WIDTH

6.7.1 GENERAL

Prior to this investigation, most evaluation of the step effect was based on scenes displayed on color CRTs. On a color CRT, the spot size must be such that each scan line has a width equal to the center-to-center distance between scan lines so that all color-dot triads are scanned. On a black-and- white CRT, the spot can be focused smaller. In this investigation, a black-and-.) CRT was used to have most direct applicability to ASUPT. An unexpected result was that this factor alone resulted in noticeable improvement. This was first noticed when an edge was produced with slope which gave significant step effect on the color CRT, and it was found to be much less noticeable.

The explanation for this improvement is thought to be as follows. Note on Figure 41 the steps with the figure drawn to simulate a color CRT type of situation. On Figure 44 (a), the same edge is shown with the finer scan lines usable with a black-and-white CRT. It seems that the eye has a tendency to interpret the terminations of the narrow lines as a continuous edge without steps. Comparing Figure 43 and Figure 44(b) shows this even more clearly, although in neither case is this effect as apparent in the figures as in the actual displays

6.7.2 SIMULATION

Since all scenes were taken on the black-and-white monitor, they all include this effect. This does not allow a comparison. An attempt was made to provide a comparison by defocussing the spot on the monitor when still photographs were taken. The available degree of control did not allow truly simulating the effect shown on color monitors, so the true degree of the difference was not shown.

6.7.3 RESULT

Since the delivered ASUPT system will use black-and-white CRT's, this effect can be expected to be beneficial for ASUPT.

6.8 GENERAL EVALUATION

The results discussed previously give a strong indication that a combination of techniques—optimum selection of transition time, black-and-white CRT, 1000-line system, judicious contrast selection, and scan line orientation optimized for the application-will leave only a small residual effect of negligible significance in operation. This is best indicated on the airport sequence with one-element transition time and 1000-line simulation. This scene does not have contrast optimized, but it does have a variety of contrasts for evaluation. It does not have scan line orientation optimized to the horizon, but the variety of edge slopes combined with the roll of the scene provides evaluation of the full range of relative orientations.

6.9 VARIABLE TRANSITION TIME—IMPLEMENTATION

At one time the concept of implementing a transition time equal to edge slope appeared quite attractive in theory. When it became obvious that this technique, even if imple-

124

Figure 43. Effect of Element Size Reduction
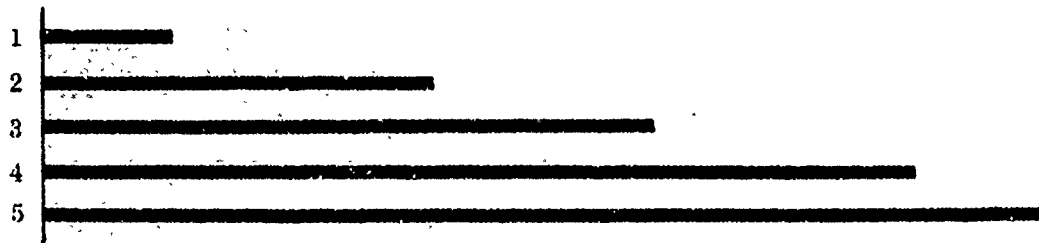
(a)

(b)

Figure 44. Scan-Line Width Effect

mented, would not eliminate step effect for near-vertical edges. It became far less attractive. Nevertheless, if it could be easily implemented it would almost completely eliminate all cases except the near-vertical, and if the circuitry had a minimum one-element transition time, it would do at least as well on the near-vertical case as a single fixed delay. A brief investigation was, therefore, made into the feasibility of implementation.

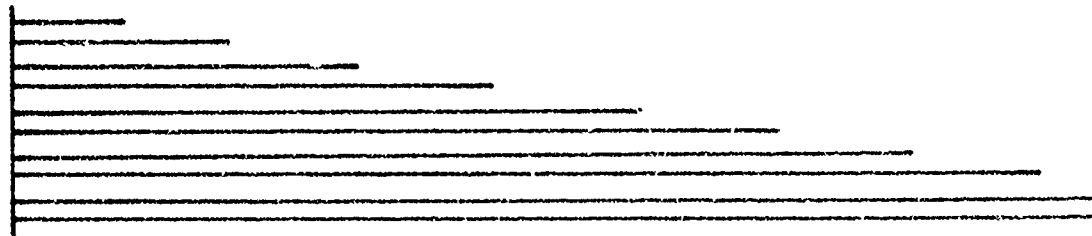Implementation would proceed somewhat as follows. Consider the simple case of a horizon or other near-horizontal edge as shown in Figure 15. The slope is established by the intersections of the edge with the raster lines at discrete element numbers on each raster line. The element number at which transition should start on each raster line should ideally be a function of the slope. Transition should start before the calculated crossing by an amount equal to one-half the interval between crossings on two successive raster lines.

While this would work if there were only one edge, consider complicating factors. In Figure 45, consider the almost horizontal edge shown. Applying these rules, the color transition on scan line 12 will start on element number 57 and be completed on element 63. If the face below the line is red and that above is green, then the color for element 60 will be a yellow (not on ASUPT, of course, but this part of the discussion is more general). Now consider Figure 46, where we have a brown building sticking above the horizon (the long edge). Here we do not want to start a transition at 57 but at 60. Further at 60, there must be a short transition to yellow, which is not a color of any face in the environment, followed by a transition to green with 3 element-time transition time.

That case was simple. Now suppose the edge of the building, rather than being vertical on the screen, had been at a slope of, say, two elements per line. Then the first rules covered above would have directed a transition starting at element 59 and ending at 61 from its color to—what?

An attempt to formulate general rules covering a variety of edges with various slopes influencing the same group of elements leads to indications of extremely complex circuitry. This, combined with the fact that there are strong indications this may not be necessary leads to the conclusion that it is not a serious candidate for inclusion in an operational system.

Incorporation of a single transition time applicable to all edges in the scene is, however, quite simple and inexpensive to implement. Further, the degree of element smoothing can easily be made controllable in the event there should be any advantage in having this—if, for example, different transition times might be optimum for different types of missions.
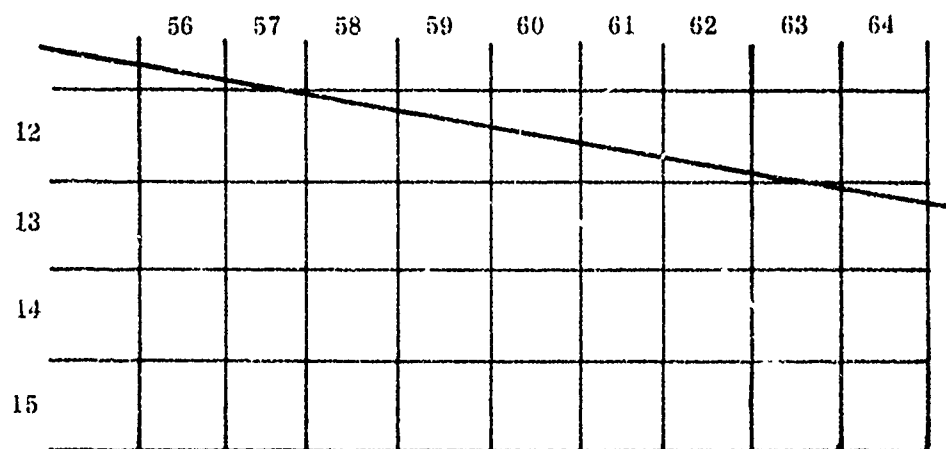
Figure 45. Single Edge
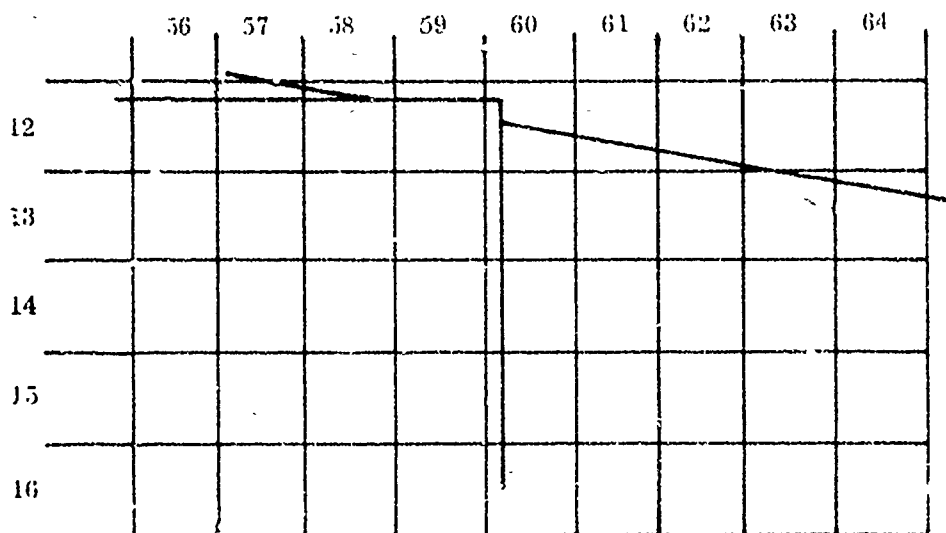
Figure 46.   Edge and Building

APPENDIX I

CRT SPECIFICATION

TYPE 36M10P-M CATHODE RAY TUBE

The requirements and tests of the latest issue of specification MIL-E-1 shall apply except as otherwise required herein.

The numbers in the "reference" column of this specification refer to paragraphs and methods of the MIL-E-1E specification which outline the procedures to be used; deviations or other procedures used are noted.

Description: 36-inch diameter, magnetic deflection and focus projection CRT with aluminized screen. (Phosphor to be selected.)

Ratings:	El	Ec1	Ec2	Eb	Ehk		Rgl
	V	V dc	V dc	V dc	V dc		Meg
Absolute							
Maximum:	6.3 + 10%	0	2,000	42,000	300		1.5
Minimum:	—	-300	—	10,000	-300		—
Test	6.3	Adjust	1,000	38,000	Part 1 and Part 2		
Conditions:	6.3	Adjust	2,000	38,000	Part 3		

Paragraph and Method Reference	Test	Conditions		Limits		
			Sym	Min	Max	Units
	GENERAL					
3.7	Marking	Note 1				
D-20	Dimensions	Per Figure (TBD)				
E-50.3.1	Preheating					
E-50.2	Holding Period					
3.1.1	Performance	Note 2				
	DESIGN TEST					
E-1331	Interelectrode Capacitance	K to all	C:	—	9	μμf
		G1 to all	C:	—	10	μμf
		G2 to all	C:	—	12	μμf
—	Contract Ratio	Note 6				

130

Paragraph and Method Reference	Test	Conditions	Sym	Min	Max	Units

ACCEPTANCE INSPECTION PART I (PRODUCTION)

Paragraph and Method Reference	Test	Conditions	Sym	Min	Max	Units
E-5201	Voltage Breakdown	Eb = 42,000 V Ec2 = 2,000 V				
E-5206	Gas Ratio		Gr:	—	50	μa
E-5101	Neck Straightness	Note 3				
E-5106	Blemishes	Note 4				
E-5231	Spot Position			—	1,000	Inch
E-5236	Zero Bias Anode Current			—	7000	μadc
E-5251	Grid No. 1 Leakage			—	3	μadc
E-1301	Heater Current		II:	540	660	ma
E-5101	Side Terminal and Base Alignment Vacant Pin No. 3			-5	+15	Degrees
E-5216	Stray Emission	Eb 42 Kv Ec2 2,000 V With normal raster scan		—	0.2	Ft.L.
E-5251	Heater-Cathode Leakage			—	10	μadc
E-5251	Grid No. 2 Leakage			—	?	μadc

ACCEPTANCE INSPECTION PART II (PRODUCTION)

Paragraph and Method Reference	Test	Conditions	Sym	Min	Max	Units
—	Light Output	Note 5	Light	1000	—	Ft.L.
—	Modulation + Cathode Current vs. Light Output	(Note 7)	Ec1:	—		Vdc
E-5241	Grid Cutoff Voltage		Ec1:	-200	-280	Vdc
E-5226	Line Width "A" Light 1000 Ft.L.		Width:	—	0.037	Inch
E-5201	Cathode Current Light 1000 Ft.L.			—	6000	μa

ACCEPTANCE INSPECTION PART III (PRODUCTION)

Paragraph and Method Reference	Test	Conditions	Sym	Min	Max	Units
E-5251	Grid Cutoff Voltage			-180	-250	Vdc
—	Light Output	Note 5		1000	—	Ft.L.
E-5241	Focus Coil Current			TBD	TBD	ma
E-5226	Line Width	Light 1000 Ft.L.			0.037	Inches
—	Modulation and Cathode Current vs. Light Output	Note 9			0.037	Inches

Paragraph and Method Reference	Test	Conditions	Sym	Min	Max	Units

END OF LIFE PERFORMANCE LIMITS

Paragraph and Method Reference	Test	Conditions	Sym	Min	Max	Units
4.7	Life Tests					
E-60	Life Test CRT	Group C Eb = 38 Kv Ec2 = 1,000 V Ib = 1,000 μa Focus Raster	5:	500	—	Hours
4.7.3.1	Life Test End Point	Light = 300 Ft. L. (Note 5)				
Eb = 38,000		Line Width "A"	Width:	—	0.040	Inch
Ec2 = 1,000		Modulation	Ec1:	—	200	Vdc
		Cathode Current	iK:	—	7000	μadc

NOTES

1. The tubes shall be marked as follows: Thomas 36M10P-M, serial number, contract number, customer part number, and code date. All tubes shall *be* marked in a legible and permanent manner on the base or bulb.

2. In addition to the tests and requirements listed herein by reference to paragraphs in the basic section, the following tests and requirements of Specification MIL-E-1E shall apply: 3.3, 3.4, 3.4.1, 3.4.3, 3.7, 3.8, 4.3, 4.4, 4.8, and 4.9.21.

3. The cylinder shall be 5 inches long and have a (TBD) inch maximum inside diameter.

4. The center 20 inches of the faceplate shall contain no defects, such as bubbles or seeds which are larger than 0.050 inch, and not more than ten defects of smaller size if seeds less than 0.010 inch are discounted. The remainder of the faceplate shall contain no such defects larger than 0.040 inch and the aggregate number of defects shall not exceed 25 over the entire useful faceplate area, nor more than three over any 3.0 inch diameter, if all such defects less than 0.010 inch are discounted.

5. As measured on a full screen 1000-line raster at the tube face center using a Weston 759 light meter, or equivalent.

6. Contrast ratio is defined as the brightness of a raster (approx. 14" x 3") located at the tube face center minus the background brightness divided by the background brightness. The background brightness shall be measured on an unexcited portion of the tube face in the vicinity of the raster beyond the first halation area.

7. Cathode currents and modulation voltages for 200 Ft. L. increments to 1000 Ft. L. with conditions noted in Note 5.

8. Measured as in Note 5.

9. As in Note 7

132

Spec. No.	Date Issued	Revision	Change
36M10P-M	5/1/71		

TEST DATA SHEET

INSPECTORS:

TEI _____

LINK _____

G.S.I. _____

Paragraph and Method Reference	Test	36M10P-M		Test Data Sheet	
		S/N	Min.	Max.	

Paragraph and Method Reference	Test	S/N	Min.	Max.
ACCEPTANCE INSPECTION (PRODUCTION)				
E-5201	Voltage Breakdown			
E-5206	Gas Ratio	µa		0.25
E-5101	Neck Straightness			
E-5106	Blemishes			
—	Light Output Part II	Ft. L.	1000	
	Light Output Part III	Ft. L.		
E-5223	Modulation and IK Part II			
L-5201	Cathode Current Part III	µa		6000
E-5231	Spot Position	In.	1 0	
E-5236	Zero Bias Anode Current	µa		7000
E-5241	Grid Cutoff Voltage Part II	Vdc	-200	-280
E-5241	Grid Cutoff Voltage Part III	Vdc	-180	-250
—	Focusing Coil Current Part II	ma	TBD	TBD
—	Focusing Coil Current Part III	ma	TBD	TBD
E-5251	Grid No. 1 Leakage	µa		3
E-5226	Line Width "A" Part II	in		0.037
E-5226	Line Width "A" Part III	In.		0.037
E-1301	Heater Current	ma	540	660
E-5101	Side Terminal and Base Alignment	Degrees	15	-15
E-5216	Stray Emission	Ft. L.		0.2
E-5251	Heater-Cathode Leakage	µa		10 0
E-5251	Grid No. 2 Leakage	µa		3 0
	Dimensions	In.		
E-5223	Modulation Part III			

APPENDIX II

ADVANCED SIMULATOR FOR
UNDERGRADUATE PILOT TRAINING (ASUPT)

COMPUTER GENERATED IMAGERY (CGI)
ASSUMED MULTIPLEXED DISPLAY
REQUIREMENTS

NOTE

This document was developed as an internal requirements
document by the contractor in order to define the modes of
multiplexed operation as a baseline for guidance in the per-
formance of this contract.

3

1.0 PURPOSE

This document defines the assumed additional performance requirements placed upon the Advanced Simulator for Undergraduate Pilot Training (ASUPT) Computer Generated Imagery (CGI) System to service the visual displays of two cockpit display stations operating in independent modes.

2.0 APPLICABLE DOCUMENTS

To be specified.

3.0 PRIMARY PERFORMANCE REQUIREMENTS

3.1 SYSTEM OPERATING MODES

The multiplexed ASUPT CGI System, hereafter designated the "system," shall provide the capability of operating the visual displays of two cockpit display stations in non-multiplexed or in multiplexed modes of operation as selected by a system instructor/operator.

3.1.1 Non-Multiplexed Modes

Non-multiplexed system operation shall provide for operation in an individual mode or a master-slave mode as selected by a system instructor/operator.

The individual mode shall provide for operation of either one of the two cockpit display stations alone with the selected station being capable of utilizing the total system edge capacity at normal scene refresh and update rates of 30 scenes per second.

The master-slave mode shall provide for operation of either one of the two cockpit display stations in the individual mode with the other station acting as a slave to receive the same display presentation.

3.1.2 Multiplexed Modes

Multiplexed system operation shall provide for operation either in a time-multiplexed mode or in an edge capacity-multiplexed mode as selected by a system instructor/operator.

The time-multiplexed mode of operation shall provide for concurrent independent operation of two station displays with each display capable of utilizing the total system

edge capacity at a 30 scene-per-second refresh rate and a 15 scene-per-second update rate.

The edge capacity-multiplexed mode of operation shall provide for concurrent, independent operation of two cockpit displays at scene refresh and update rates of 30 scenes-per-second wherein the total system edge capacity is allocated between the two cockpit displays as determined by an instructor/operator.

3.2 SYSTEM INTERFACE

A compatible signal interface shall be provided which will be capable of the required data transfer at a 30-transfer-per-second rate to service either cockpit display in the non-multiplexed modes of operation or to service both cockpit displays individually in the edge capacity-multiplexed mode of operation. It shall be capable of the required data transfer at a minimum of 15 transfers per second for each cockpit display in the time-multiplexed mode of operation.

The system shall provide the capability for interfacing with and driving concurrently the video display presentations at either one or both cockpit display stations in accordance with the operating modes defined in Paragraph 5.3 of the report.

3.3 DUAL SIMULATION DISPLAY PROBLEM OPERATION

The system shall provide the capability for generating and storing, and for processing concurrently two simulation display problems with the two simulated aircraft operating in the same or independent environments in accordance with the operating modes defined in Paragraph 5.3 of the report.

3.4 INSTRUCTOR/OPERATOR CONTROL AND DISPLAY

The system shall provide the capability to allow the instructor/operators to accomplish those additional control and display functions that are related to the operational capability at the flight simulator instructor/operator stations defined in Paragraph 5.3 of the report.

3.4.1 Advanced Instructor/Operator Station

This station shall provide for the following additional control and display functions:

    a.   The selection of non-multiplexed and multiplexed modes of operation.

    b.   In the edge capacity-multiplexed mode of operation, the selection of the scene content to be allocated to the simulation display problem being

137

handled by each cockpit display station (i.e., the percentage of total system edge capacity to be allocated to each station display) by console control and/or display problem selection.

    c.   As appropirate to the operating mode selected, the selection for display at each one of two pairs of CRT monitors of any two channels from the seven display channels at either cockpit display station.

    d.   The control of either simulation display problem in progress, independent of the other (i.e., independent control of program interruption, freeze, replay, and reinitialization, etc.).

    e.   The display of program operation and equipment status information that are related to multiplexed operations.

    f.   As consistent with this station's specified operational capability, the provision for allowing off-line and on-line environment and program generation and modification that are related to multiplexed operations.

    g.   The independent power on-off control of any duplicated equipment required for multiplexed operation and not used in the operating mode selected shall be a desired control feature.

3.4.3   Conventional Instructor/Operator Stations

Each one of two stations shall provide for the following additional control and display functions:

    a.   As appropriate to the operating mode selected, the selection of any two channels from the seven display channels at either cockpit display station for display at a pair of CRT monitors.

    b.   The control of either simulation display problem in progress, independent of the other (i.e., independent control of program interruption, freeze, replay, and reinitialization, etc.).

    c.   As consistent with these stations specified operational capabilities, the display of program operation and equipment status that is related to multiplexed operations.

3.4.3   Cockpit Instructor/Operator Stations

Each one of two stations shall provide for the following additional control and display functions:

    a.   The control of either simulation display problem in progress, independent of the other (i.e., independent control of program interruption, freeze, replay, and reinitialization, etc.).

135

b.   As consistent with these stations specified operational capabilities, the display of program operation and equipment status that is related to multiplexed operations.

3.5   SYSTEM MAINTENANCE AND OPERATIONS PROVISION

The system shall provide the capability to allow a system operator to accomplish those additional control, display, diagnostic, and maintenance functions that are related to the operational capability defined in Paragraph 3.1.2 (of this Appendix) at a System Maintenance and Operations Station.

This station shall provide for the following additional functions:

a.   The selection of non-multiplexed and multiplexed modes of operation.

b.   In the edge capacity-multiplexed mode of operation, the selection of the scene content to be allocated to the simulation display problem being handled by each cockpit display station (i.e., the percentage of total system edge capacity to be allocated to each station display) by console control and/or display problem selection.

c.   As appropriate to the operating mode selected, the selection for display at each one of two pairs of CRT monitors of any two channels from the seven display channels at either cockpit display station.

d.   The control of either simulation display problem in progress, independent of the other (i.e., independent control of program interruption, freeze, replay, and reinitialization, etc.).

e.   The display of program operation and equipment status information that is related to multiplexed operations.

f.   As appropriate to the operating mode selected, the independent application of each one of the two joystick control functions to the simulation problems being run on either one or both of the cockpit display stations.

g.   The capability of conducting diagnostic and maintenance activity that is related to multiplexed operations.

h.   As consistent with this station's specified operational capability, the provision for allowing off-line and on-line environment and program generation and modification that are related to multiplexed operations.

i.   The independent power on-off control of any duplicated equipment required for multiplexed operation and not used in the operating mode selected.

3.6   BASIC SYSTEM IMPACT

The system performance requirements specified herein shall be satisfied without caus-
ing any significant impact on the modularity, flexibility, and/or conceptual design of
the basic ASUPT CGI System.

3.7   TEST AND DIAGNOSTIC PROVISIONS

Software and hardware to support test and diagnostic operations shall be provided as
necessary to extend the non-multiplexed ASUPT CGI preventive and corrective mainte-
nance capabilities in a similar manner to cover multiplexed system operation.

140